Opening Session

INTRODUCTORY REMARKS

By ALBERT L. COCHRAN, *chairman, Subcommittee on Sedimentation, Inter-Agency Committee on Water Resources*

The subject of this conference is an important one. It relates to a problem that has a major impact on the development of water resources. We are all aware that the future prosperity of this nation or any other is dependent upon the efficient planning, design, construction, and operation of facilities required for optimum utilization of water resources. Sedimentation is a malignant growth that dissipates the effectiveness of our reservoirs, floodways, navigation channels, and harbors. It seems incurable at present, but is already responding to preventive measures in some degree. Through increased knowledge of sedimentary processes and the influences that govern these, we can avoid many errors in design and possibly direct the forces involved toward useful purposes in preserving rather than destroying lands and river improvements.

You will find that many of the papers prepared for this conference deal with current problems and immediate practical solutions, whereas others relate to research activities needed to improve future solutions. In the opening session, principal emphasis is being placed on educational and research needs.

WELCOMING REMARKS

By W. ALTON BRYANT, *vice chancellor, The University of Mississippi*

Mr. Chairman and Delegates:

It is a privilege to welcome you on behalf of the University of Mississippi. The University is vitally concerned with the research which you are carrying on in the area of soil sedimentation. The implications for the improvement of our economy and our society are tremendous.

The establishment a few years ago of the Sedimentation Laboratory just off the Oxford campus of the University of Mississippi is proving of great value to the University. The laboratory has brought to it first-class scientists who have contributed to the intellectual and social life of the community and who have made direct contributions to the teaching and research programs of our science departments. Since a true University is a community of scholars, the staff of the laboratory has been a real addition to our faculty.

The Waterways Experiment Station at Vicksburg, co-host with the Sedimentation Laboratory of this Conference, has over the years gained national and international recognition for technical ability and excellence in dealing with problems of control of major rivers such as the Mississippi.

I want to express my appreciation to the sponsors of the Conference, for making it possible for me to meet with you here today and have a brief part on your program. I am delighted that your itinerary will take you to Oxford and Vicksburg, where you will have an opportunity to see the University, the Sedimentation Laboratory, and the Waterways Experiment Station.

REFLECTIONS ON FIRST FEDERAL SEDIMENTATION CONFERENCE

By CARL B. BROWN, *watershed specialist, Soil Conservation Service*[1]

I am deeply grateful for your invitation to make a few opening remarks at this Second Federal Inter-Agency Sedimentation Conference. You know that I am no longer a member of your professional group, although I worked for some 15 years in your field and was a party to organizing the Sedimentation Subcommittee of what is now the Federal Inter-Agency Committee on Water Resources. As chairman of the subcommittee in 1947, I had the privilege of opening the first Inter-Agency Sedimentation Conference.

In order to become somewhat better acquainted with your progress, I leafed through the annotated bibliographies prepared jointly by the subcommittees on Hydrology and Sedimentation for the years 1950 through 1958. Many hundreds of entries deal with sediment transport and sedimentation. In the early 1940's a comprehensive survey of all the existing literature, both domestic and foreign, back to

[1] Died May 5, 1963.

about 1850 on the subject of reservoir silting showed less than 150 references excluding news notes. Probably nearly that many titles, worldwide, now get into the technical literature every year on this aspect of sedimentation.

To take another point of reference, when I came into the Washington office of the Soil Conservation Service in June 1935 to direct a program of reservoir sedimentation studies, my first effort was to find out what had been done and what was known about the subject. My first discovery was that there was no compilation of existing reservoirs in the United States, much less any significant knowledge about the effects of sedimentation on them. I spent many a hot day that summer in the old offices of the Corps of Engineers in the World War I Temporary War Department Building on Constitution Avenue, which incidentally is still there, searching through the Corps files of appendices of the 308 reports to glean what information they contained. We started in that year a card index file of significant items of information on the reservoirs of the United States. It was greatly expanded by the WPA library research project, which we supervised in New York City from 1937 to 1941. This file was subsequently made available to the U.S. Geological Survey and, together with their own efforts in this field, eventually resulted in publication of a substantial inventory of data on most reservoirs larger than farm pond size.

Our literature review in 1935 turned up some results, often more qualitative than quantitative, on silting in about 40 American reservoirs, and a few in other countries. The inventory of reservoir sedimentation surveys dated 1953, issued by the Sedimentation Subcommittee, contains data on about 700 reservoir and debris basin sedimentation surveys. This inventory is now being revised by the Agricultural Research Service for the Subcommittee. The revision will contain an additional 300 new surveys, making a total of about a thousand surveys to date.

In 1935 there was only a meager collection of records of the sediment load of streams. Because of lack of understanding of the principles of sediment transport and the crude sampling equipment, many of these records were of highly questionable value. Prior to 1935 there had been only very few laboratory studies of sediment transport in this country. Most of the pioneering in this field had been done in the European universities and institutes. In 1935, the Soil Conservation Service established a Sediment Transport Laboratory in cooperation with the California Institute of Technology at Pasadena and a Bedload Research Station at Greenville, S.C. Pioneering studies at these locations were made by such present day leaders in the field as Vito Vanoni of "Cal Tech," Hans Albert Einstein and Joe Johnson of the University of California at Berkeley, Hunter Rouse of the University of Iowa, Nephi Christenson of Cornell, Alvin Anderson of Minnesota, and many others. Their early work, together with the pioneering work of Professor Lane in Colorado, Dr. Straub in Minnesota, and several able scientists at the Corps of Engineers' Vicksburg Laboratory generated a great forward push in sediment transport research.

When the first sedimentation conference was held at Denver in 1947, there was a climate of enthusiasm. World War II had been finished a little more than a year. A great national effort at water resources development appeared in the offing to offset the anticipated depression and vast unemployment that the economists of the day confidently predicted. The vast Pick-Sloan Plan had been approved for the Missouri River Basin and was getting under way. Surveys were being resumed under increased budgets in many other river basins by the Federal agencies. Also the Federal agencies were beginning to cooperate more closely than ever before under the Quadripartite Agreement of December 1943. Technical interagency subcommittees had been created to provide a mechanism for accomplishing many objectives that had not previously been possible.

The papers offered at the 1947 conference substantially summarized or at least referred to the scope and extent of our problems and our knowledge in the field of sediment transport and sedimentation. The proceedings of this conference remain a valuable document, for more than just historical reasons, in the library of anyone actively working in this field.

After the passage of 15 years, how can we assess what has happened in this field relative to needs, goals, and objectives as they were foreseen in 1947. Most of you here have been directly and intimately associated with the sedimentation field for much if not all of the last 15 years. My own assignments in the Soil Conservation Service led me progressively away from the field, and for the last 10 years I have been able to visit with most of you only occasionally. So my perspective is now from the standpoint of a program planning specialist in the water resources field who is looking from the outside toward you in the setting of what you are providing that we need for sound planning. It would be far beyond my capacity to try to present a comprehensive or even balanced review of all the pluses and minuses of the last 15 years. But I would like to leave with you three impressions and recommendations.

1. Although our knowledge of sedimentation conditions and processes has greatly advanced

in the past 15 years, as shown by the vast increase in publications, data records, laboratories, etc., it has not been commensurate with the increasing worldwide need for more sound technical information to support the development of optimum water resource plans. We are still paying every year many times the cost of needed research and investigations by adding costly factors of safety in the planning and design of our water resource improvements. There are probably two basic reasons for this. One of them has always been with us — that is the failure of administrators and program specialists to recognize sufficiently the needs for financial support because of their own lack of technical understanding. It is my impression that this situation is improving, however, because of the changing attitude in this country toward research and development. Forces outside of the field of water resource development have found it so profitable to enlarge greatly budgets for research and development that administrators in this field, as well as Congressional Committees that are concerned with appropriations for it, have been increasingly convinced that research pays.

To illustrate, the sedimentation and hydrology research in the Department of Agriculture was started in the Soil Conservation Service in 1935 with funds allocated from public works appropriations. After the projects were formulated, the initial installations built, and a highly competent group of young scientists had been assembled, we had to go before appropriations committees. Progressively, from about 1937 until after 1950, funds for this type of activity were whittled down. In 1953 the research work of the Soil Conservation Service was transferred to the Agricultural Research Service and reorganized. About this time appropriations for research and development in nuclear energy, electronics, space, medicine, and other fields began an upward spiral, the limits of which are not yet in sight. Administrators in the Department of Agriculture and members of the appropriations committees concerned with agriculture began to recognize their field of interest was being short-changed relative to progress in other fields. In this climate there has come about within the past several years a strong competition for the establishment of new research facilities. One of the earliest of these new facilities is the fine sedimentation laboratory at Oxford, which many of you will see in connection with this conference, under the direction of Carl Miller.

On the other hand, the vast expansion of research and development in the nuclear and space sciences appears to have resulted in a marked decline in the interest of graduate students in making careers in the field of sedimentation and hydrology. This constitutes one of the gravest problems of concern to this group. Heads of departments and research laboratories across the country tell me that it is exceedingly difficult to induce young engineers to take advanced studies in sediment transport and hydrology. The supply coming out of the institutions is nowhere near commensurate with future needs. With the total number of young scientists with doctors' degrees or even masters' falling far short of the national needs, this problem seems destined to become more critical. It is high time that a group such as this considers seriously ways and means by which the work in your field can be given a greater measure of glamour or other inducements that will upgrade its rating in the space age. This is my first recommendation.

2. My second impression is that we have a great storehouse of useful information that has not yet been put in a form needed by program and project planning people. Your efforts as technical specialists have been directed by administrative and other considerations largely toward (1) establishment of new research facilities, and (2) the solution of specific problems that are critical time-wise. A great deficiency has developed in the analyses and interpretation of existing data. One of the best examples, of course, is the many thousands of station years of records of sediment loads of streams all over the United States.

The Sedimentation Subcommittee is to be commended on its work of compiling statistics on the existence of these records, their duration and quality, but this alone obviously does not provide what the planner requires. Even if these individual records have been computed and published in terms of annual tonnage of sediment, the planner still has little more than an average for a generally short period of time with some indication of upper and lower limits. What could be done with this vast array of records in an Institute devoted to utilizing the most advanced statistics of probabilities and equipped with the latest types of computers needed to test various equations with respect to correlation coefficients that might be obtained? In this area I recommend that the conference give serious consideration to ways and means by which the utilization of all forms of field station and survey records may be compiled, computed, analyzed, and interpreted. This activity deserves fully as much attention as the much needed basic research on the dynamics of sediment transport.

3. Sediment transport and sedimentation need to be glamourized as a national problem. This need has been almost overlooked in the past 15 years. It should be a never-ending effort.

Do not get too deeply buried in your research and technical studies to overlook the fact that continuous publicity focused at the seats of authority and control are needed to create an adequate awareness of the requirements in your field. This is just a part of every day life in this country.

From the time the Department of Agriculture published a bulletin by the late Hugh Hammond Bennett in 1928 entitled "The National Menace of Soil Erosion," there has been no letup in the application of time and talent to the compilation, writing, and publication of useful public information on why soil erosion needs to be controlled and how it can be done. As the years have passed, this effort has been expanded to embrace the need for water conservation on farms and ranches, for better woodland management, for preservation of fish and wildlife resources, how to provide adequate recreational requirements on the rural private lands of America, and how to achieve all of these purposes through multipurpose watershed development.

This conference should consider a bulletin prepared by interagency effort through the Sedimentation Subcommittee which might have some such title as "The National Cost of Sedimentation." Pages 3 to 7 of the Proceedings of the 1947 sedimentation conference contain an outline of this kind of information. Inquiries come to the Soil Conservation Service almost every week for facts of this kind. For example: What is the annual cost and what is the annual tonnage of material dredged from the harbors of the United States? What is the annual cost of removing sediment in the purification of surface water supply? And scores of similar questions. Current news releases and bulletins coming from the Department of Agriculture are still quoting sources largely more than 10 years old.

Let me remind you also that conferences such as this serve or should serve publicity as well as technical purposes. Instead of being 15 years apart they should be held every 2 or 3 years.

Again let me thank you sincerely for your invitation to appear on this opening day of your program and to wish you well in your efforts to bring more light and knowledge into what is perhaps the most complex field in the whole area of water resource development.

SPECIAL MESSAGE

By E. W. LANE, *hydraulic engineer (retired)*[1]

Fellow scientists, I regret that I am unable to be with you. However, I welcomed the opportunity to present this message to you — especially because of our common interests and my past association with many of you. My comments, many of which are not new, deal with ideas and concepts which I think bear repeating.

The Missouri River was called "The Big Muddy" by the Indians. The Colorado River delta indicates that this river in recent geologic time has transported considerable sediment. At the time DeSoto discovered the Mississippi, the river was in flood, making it necessary to wait for a drop in stage before it could be crossed. George Rogers Clark observed a great flood on the Wabash River in Revolutionary War times. The history of Fort Pitt cites the occurrence of a record flood on the Ohio River. Even if man were able to restore all streams to their virgin conditions, large floods, transporting millions of tons of sediment, would still be a common occurrence. In most instances man's effect on the magnitude of floods, sediment discharge, and channel stability of our major rivers has been rather puny, particularly when compared with such a natural catastrophic event as was required to form the Grand Coulee by the Columbia River.

Nevertheless, we must recognize an ever increasing urgency to preserve and utilize more effectively our extremely valuable natural resources — land and water. To achieve any semblance of success, such problems as the following must be recognized and solved promptly:

1. The public and its elected representatives should be urgently advised of all aspects of water and land utilization, the need for accelerated, coordinated research efforts, and the consequences of laxity.

2. The advent of team effort must be welcomed by all concerned. The complexity of land and water resources problems, which are intimately interrelated, will require the combined efforts of our best scientists from the engineering, the physical and biological sciences, and the social science fields.

3. An overall coordinated plan must be developed to achieve the essential goals. This will require the cooperation of many Federal and State institutions and agencies, and our educational institutions, as well as international cooperation.

To put the need for additional funds to achieve success into proper perspective, consider the money spent thus far to achieve our current knowledge of rocketry, space travel, and communication. The cost of Telstar and similar

[1] Died Aug. 10, 1963.

projects alone is discussed in terms of billions of dollars. Certainly, the importance and complexity of the problems we face in the field of sedimentation are as difficult and may even be of greater significance for the survival of man.

The problems of sedimentation, which are being considered at this conference, are a significant and vital part of the broader aspects of water and land utilization discussed in the foregoing paragraphs. Many phases of sedimentation have defied rigorous mathematical analysis. The determination of correct numerical answers is difficult because of the number of variables involved. We must take stock of the results obtained and make use of these results. Insofar as possible we must avoid the use of questionable approximations in making important decisions.

Since the last meeting in Denver in 1947, notable advancements have been achieved in the areas of land erosion and control, and in sedimentation in streams, estuaries, harbors, and reservoirs. With the advent of intensified activity, increasing interest, improved instrumentation, and ever-increasing development of new methods of analysis, computer programming, and better coordination of efforts, much should be possible with regard to educating the public, improving existing theories and concepts, and conceiving new theories. Most of our studies thus far have been oriented toward a look at the average conditions and gross mechanics, using simplified systems. Much has been achieved with this approach. To advance our knowledge further, it seems essential to look more closely at the inner mechanics of sedimentation. This will require breaking the gross problem into its components and then critically examining these components.

Some of the important problems that must be studied to advance further our knowledge of sedimentation include:

1. The role of the individual variables such as velocity, depth of flow, temperature, and concentration of wash load.

2. The physical explanation of the development of bed forms, including why they develop and why they vary from ripples to dunes to plane bed to antidunes — including combinations of these. This knowledge is essential, in order to understand resistance to flow, sediment transport mechanics, and the behavior of canals and rivers.

3. The importance of turbulence and diffusion has long been discussed and recognized as having an important bearing on a more fundamental concept of sedimentation. Thus far we have been hampered by not only a lack of a satisfactory theory of turbulence, but also by a lack of adequate means of measuring its properties in water.

Other areas requiring further work of a fundamental nature include:

1. Forces on particles — such as lift and drag.

2. Improved methods of describing the significant characteristics of sediment. For example, our knowledge of fall velocity of particles is very incomplete.

3. Better methods are needed to sample sediment being transported. For example, we need to devise more adequate means of measuring contact load in alluvial channels.

In conclusion, it should be emphasized that the results of our studies are essentially useless unless they are published. Even though we may not have answered a particular problem to our complete satisfaction, our results may save other workers considerable time and expense if they are published. Finally, results should be published, using available avenues that are widely circulated, read, and respected, both nationally and internationally, that provide coworkers an opportunity not only to study the results of our work but also to discuss these results.

The foregoing statement includes ideas and thoughts which I have discussed recently and in the past with Daryl B. Simons[2] and Maurice L. Albertson,[2] who have helped me by assembling the ideas into written form. Because of my present illness, it would not have been possible for me to prepare this without their help.

KEYNOTE ADDRESS

By L. C. GOTTSCHALK, *staff geologist, Engineering Division, Soil Conservation Service*

Floods and erosion are natural conditions which have existed throughout geologic time. With the advent of Man, the surface of the land has undergone a progressive change. Much of the natural, protective vegetation has been removed or depleted. The soil mantle has been disturbed by tillage and construction activities. Highways, streets, and buildings have been built, creating runoff from areas where formerly the rainfall percolated into the soil mantle.

With increased population comes greater demands for food and fiber and more intensive land use. Increased population means more buildings, more highways, more urbanization. The net result is greater erosion and more fre-

[2] Colorado State University, Fort Collins.

quent and higher floods and more and more sediment. History records the decline of ancient cities, even ancient civilizations, because the inhabitants could not cope with the erosion and sediment problems.

In this day and age, with our ability to produce power and machines and our technical advances and ingenuity, we no longer find ourselves completely helpless to meet Nature's assaults. But the people of the United States, the taxpayers, farmers, home owners, and industrialists, either directly or indirectly, are paying a staggering price for wasted soil and water resources. The current flood damage in the United States is estimated at more than $900 million annually, of which a sizable portion is chargeable to sedimentation. In Johnstown, Pa., after the flood of March 17, 1936, it cost $3,870,000 to remove the sediment and debris from streets and cellars. At present-day prices, this bill would be considerably higher.

Sediment accumulates in our channels, waterways, and harbors, where the cost of removal is high. Infertile sediment damages crops and reduces the productivity of our normally fertile flood plains. Sediment depletes the storage capacities of our reservoirs. At least 850,000 acre-feet of sediment is deposited in our major reservoirs each year.

The field of sedimentation has many ramifications and is complicated in scope. The geologists were among the first group of scientists in this country to be concerned about sedimentation. Their interest stemmed from a need to determine the processes involved in erosion, transportation, deposition, and consolidation of sediments to better understand the genesis and formation of sedimentary rocks. The geologists were also among the first group of scientists to be concerned about soils and about soil mechanics. But the practical solution of problems concerned with sedimentation, soils, soil mechanics, and other fields requires knowledge and skills in many different sciences in addition to geology.

Because the agricultural people needed more detailed information on soils than that which geologists could provide, a new field of soil science was developed. The same is true in soil mechanics. The engineers found it necessary to greatly expand data collection and analysis and the development of techniques and specialized equipment for evaluating the engineering properties of soil to meet requirements for design and construction of structures.

The same holds true for sedimentation. The need for more detailed information for the solution of complex problems in respect to the design and maintenance of channels, reservoirs, and other structural works of improvement has led to specialization in the field of sedimentation in the past two decades. As in other fields, the development of procedures and techniques for the solution of these problems requires studies in many disciplines. Today we have the collective efforts of geologists, engineers, physicists, chemists, pedologists, and others, all contributing to the development of knowledge needed for the solution of sedimentation problems. This is good! This is the symbol of healthy progress in any field.

Sedimentation as a field of specialization is still relatively new when compared with many other scientific fields. Important and gratifying progress is being made in this field. Today there is a much greater awareness of erosion and sedimentation problems, by both Federal and non-Federal interests, than there was when the Denver Conference was held in 1947. And today more is being done about the solution of problems than ever before.

At the time of the Denver Conference, there were no bibliographies, no inventories of sedimentation data, no standard sampling equipment and techniques, and rather limited basic data. During 1946, the year preceding the Denver Conference, sediment load measurements were being made at less than 300 measuring stations in the United States. A wide variety of sampling equipment, including soft-drink and other types of bottles, were being used to obtain samples. In 1960, sediment load measurements were made at over 800 stations in the country, using, for the most part, standard samplers and sampling procedures. There were not only more measurements in 1960, but the locations of stations gave a better representation of the different physiographic areas of the country. Furthermore, the results of these measurements are more reliable, because inherent errors due to the use of different types of sampling equipment and procedures have been largely eliminated.

The development of standard samplers and sampling procedures is a continuing function of the Federal Inter-Agency Sedimentation Project at St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minn., which is sponsored by the Subcommittee on Sedimentation. Various types of depth-integrating, point-integrating, and bed-material samplers have been designed and calibrated by this project. These are used by the Federal agencies engaged in sediment-sampling work and have been made available to non-Federal interests in this and foreign countries. The St. Anthony Falls project is now concentrating on the development of automatic equipment for sediment sampling of streams. This equipment is expected to improve further sampling results and to reduce costs. Several pilot models are being field tested at present, and their availability for general use is anticipated in the near future.

Prior to the Denver Conference, reservoir sedimentation surveys had been made on about 375 reservoirs and debris basins in the United States. The results of many of these surveys were unpublished and were filed in widely scattered places. Surveys have now been made on more than 1,000 reservoirs in the United States. The results of these surveys are neatly tabulated and will soon be available in published form.

Today we have a radioactive probe for determinating the specific weight of submerged sediment deposits. This method is fast, relatively accurate, and does not require taking a great many samples to the laboratory for time-consuming and costly analysis. Because of this equipment, many more observations of greater accuracy can be made in less time and cost than could be made by the old method, which required obtaining questionable undisturbed samples, transporting them to the laboratory, measuring, drying, and weighing them to determine the specific weight.

As of 1946, there were more than 3,000 published papers, articles, and reports on sedimentation and related subjects. These were scattered throughout various scientific journals, periodicals, proceedings, and transactions of engineering societies and elsewhere. One man in his time could not possibly search out all of this literature, much less read it. In 1950, the Subcommittee on Sedimentation arranged for the compilation of annotations of these papers and issued Bulletin No. 2, which contains references to 3,727 papers by 2,402 different authors. These articles were classified by subject matter and by river basins to facilitate greatly the use of the bibliography. Today, there are more than 4,000 published papers, and the annotations are brought up to date periodically under the auspices of, or in cooperation with, the Subcommittee.

Fifteen years ago, we talked a great deal about the factors that influence erosion, transportation, and deposition of sediment. Today, the relative influence of many of these factors is being expressed mathematically. There are now equations for estimating rates of soil erosion, for calculating sediment delivery ratios, for computing the trap efficiency of reservoirs, and for predicting rates of reservoir silting. There are equations for deriving the ultimate sediment distribution in major and small reservoirs. Soon equations will be available for predicting rates of gully head advancement and the stability of channels in cohesive materials. Many of these equations are subject to much further improvement and refinement as more information becomes available. But, like the bed material transport equations, though still subject to further refinement, they are providing answers that are far better than the use of the crystal ball. However, with all of these advancements, the need for knowledge is increasingly emphasized, which is the primary reason for this Conference.

The Subcommittee on Sedimentation has contributed effectively to the rapid advancement of sedimentation knowledge since the Denver Conference. The Subcommittee was established by action of the Federal Inter-Agency River Basin Committee in its meeting of April 25, 1946. It held its first meeting on May 28, 1946. At that time, it took over the functions of an informal Federal Inter-Departmental Committee organized for the purpose of considering the development of sediment samplers, sampling techniques, and laboratory procedure and of coordinating the work of the several agencies actively concerned with the sedimentation problem. The so-called "Iowa Reports" were sponsored by this Inter-Departmental Committee.

The parent committee, the Federal Inter-Agency River Basin Committee, had its origin in a memorandum of agreement signed by representatives of the member agencies on December 29, 1943. By letter dated May 26, 1954, the President established the Inter-Agency Committee on Water Resources to replace the Federal Inter-Agency River Basin Committee. A new charter for a continuing Subcommittee on Sedimentation was granted by action of the new Inter-Agency Committee on Water Resources at its meeting of January 25, 1955. The Subcommittee is composed of representatives of the Corps of Engineers, Department of the Army; the Soil Conservation Service, Forest Service, and Agricultural Research Service of the Department of Agriculture; the Bureau of Public Roads and Coast and Geodetic Survey of the Department of Commerce; the Bureau of Reclamation; Geologic Survey and the Bureau of Mines of the Department of the Interior; the Public Health Service of the Department of Health, Education, and Welfare; the Federal Power Commission; and the Tennessee Valley Authority.

The continuing functions of the Subcommittee are as follows:

1. Actions to facilitate and improve efforts of the participating agencies, including cooperation with State agencies where appropriate, that pertain to the collection, analysis, and interchange of sedimentation data.

2. Actions related to clarification of technical and related administrative procedures that have an important effect on sedimentation work of

participating agencies.

3. Standardization and development of technical terminology, equipment, criteria, and methodology.

4. Exchanging information on basic and applied research in the field of sedimentation.

5. Coordination of proposals of the several participating agencies and others concerned to augment bases for national policies vital to the collection, analysis, and dissemination of sedimentation data.

6. Any other action pertinent to sedimentation and of common interest to participating agencies that cannot be effectively handled by cooperating arrangements at the field level or by individual agencies.

The chairmanship of the Subcommittee is rotated annually on a mutually acceptable basis. The Subcommittee meets at least once every 2 months with more frequent meetings if the need arises. It has no permanent staff and all work accomplished by the Subcommittee is done by financial or personnel contributions of the member agencies on an "as needed" basis.

The Subcommittee has a number of important accomplishments to its credit. It sponsors the Federal Inter-Agency Sedimentation Project at St. Anthony Falls for the development, modification, and testing of sediment sampling equipment. The results of the various phases of this work are contained in more than two dozen technical reports prepared by this project.

Each year, the Subcommittee compiles a report entitled "Notes on Sedimentation Activities," which is distributed to interested personnel within the member agencies. This report summarizes activities of the Federal agencies in the field of sedimentation and provides an opportunity for the personnel of each agency to keep abreast of the current work of other member agencies as well as their own.

The Subcommittee has issued the bibliography mentioned a few moments ago and has cooperated with the Subcommittee on Hydrology and the Geological Survey, from time to time, to keep bibliographies up to date. The latest was issued by the Geological Survey in 1962. The Subcommittee has issued an inventory of published and unpublished sediment-load data in the United States as of 1949, issued a supplement to this which includes information up to 1950, and cooperated with the Geological Survey in a recent publication which brings the information up to date as of 1960. The Subcommittee has also compiled detailed sedimentation data summary sheets for all known, reliable, reservoir sedimentation surveys in the United States and issued bulletins summarizing the data for ready reference. The first of these bulletins summarized information available up to 1950. This was revised and brought up to date as of 1953. The Subcommittee has also cooperated with the Agricultural Research Service in revising and bringing this up to date as of 1961. This publication was issued in 1964.

The Subcommittee has five continuing work groups, namely (1) Sediment in Streams, (2) Sediment in Reservoirs, (3) Sediment in Estuaries, (4) Land Erosion, and (5) Personnel Problems. At each of the Subcommittee meetings, recent reports, activities, and literature pertinent to these subjects are reviewed and discussed and the information summarized in the minutes of the meeting, which are widely distributed to personnel of the Federal agencies.

This Conference, like the Denver Conference, was planned and developed by the Subcommittee. It represents still another effort to encourage and promote the interchange of information and ideas, the interchange of procedures and methodology, of basic data, and results of basic and applied research. Much time and effort has been spent in reviewing proposed papers and in developing a balanced program. The selection of papers for oral presentation was indeed difficult, since so many good papers were proposed, exceeding almost threefold the number that could be presented within the Conference time.

The papers scheduled for oral presentation at the Conference were selected by the Program Committee in collaboration with agency representatives serving on the Subcommittee. It was the objective in this procedure to assure a reasonably well-balanced coverage of agenda topics and to reflect in the program how the interests and activities of different Federal and non-Federal agencies are constituted and related. Accordingly, the papers that are presented orally are only a sample of those prepared for the Conference and included in the Conference Proceedings.

REVIEW OF RESEARCH ACTIVITIES IN SEDIMENTATION

By VITO A. VANONI, *professor of hydraulics, California Institute of Technology*

Introduction

In reviewing research activities in sedimentation, I would like to direct my attention to the developments in recent years in conformity with the theme of this conference, namely, "Fifteen Years of Progress in Sedimentation." The trend in the activities of the Federal agencies is readily apparent by comparing the program of this conference with that of the one held almost 15 years ago. It is clear that there has been progress in the development of methods of field measurement and in the general understanding of river mechanics. It is also clear that there is a close relationship between field and laboratory studies. The significant developments of the last generation are now integrated into the general technology of sedimentation engineering, and there is also evidence that the lag time between obtaining research results and applying them to the field is being reduced. The close association between engineering and research has also influenced laboratory programs to include studies of some of the interesting but complicated problems involving nonuniform flows in river systems.

In presenting the review of a field as extensive as sedimentation, it is impossible to cover all contributions and all aspects of the activities. The evaluation of work will depend largely on the experience of the reviewers, and no two reviewers would agree on the relative importance of any item. This presentation will cover work of recent years that has influenced the developments in the mechanics of alluvial channels. It is not intended to be complete, and several important phases of work in sedimentation and many worthwhile contributions will not be mentioned.

Turbulent Suspension of Sediment

The most significant contribution of the 15-year period preceding 1947 was the development and verification of the theory of turbulent suspension. In this short period the differential equation for suspension was derived by O'Brien (*39*) and its solution was published by Rouse (*41*) for the case of two-dimensional steady uniform flow. This has now become the classical suspended load distribution equation given by

$$\frac{c}{c_a} = \left[\frac{d-y}{y}\;\frac{a}{d-a}\right]^z \qquad (1)$$

where $$z = \frac{w}{\beta k \sqrt{\frac{\tau_0'}{\rho}}} \qquad (2)$$

d is the depth of the stream, c and c_a are the concentration of suspended sediment at distance y and a, respectively, above the bed, w is the fall velocity of the sediment grains, τ_0 is the shear stress at the bed, ρ is the density of the water in mass per unit volume, k is the von Karman universal constant, and β is a numerical factor. This theory was first verified by Christiansen (*12*) and Anderson (*4*) in irrigation canals and natural streams, respectively, and by Vanoni (*44*) in the laboratory. These laboratory studies also brought to light the effect of sediment on the hydraulic characteristics of a stream, which can be expressed in variations of k and β. In this connection, it is pertinent to observe that the laboratory work was advanced greatly by the invention of the recirculating flume by the late Robert T. Knapp and coworkers (*27*).

The impact of the development of the theory of suspension on the general field of sedimentation studies was very great indeed. It furnished a simple expression for the distribution of suspended load that could be applied by engineers, but an even more important impact was in its clear delineation of problems yet to be solved. In surveying the research of the last 15 years, it is clear that the development represented by equations 1 and 2 affected most of the work of this period. For example, the need for more information on fall velocity called for by the equation brought forth the outstanding work of McNown and his students on the effect of particle shape (*36, 37, 38*), particle concentration (*35*), and size of settling column (*37*) on fall velocity. This same need for information on the fall velocity of natural sediment grains was met by the pioneering work of Albertson (*3*) and by the Subcommittee on Sedimentation of the Inter-Agency Committee on Water Resources (*1*). Several studies were made to determine the effect of the sediment on turbulence and the von Karman constant and on the flow in general, among which are those of Vanoni (*45*), Einstein and Chien (*19*), Vanoni and Nomicos (*46*), and Elata and Ippen (*20*). The measurements made to check the theory also pointed up its deficiencies and led to studies to improve it, such as those by Halbrun (*22*), Hunt (*23*), and Einstein and Chien (*18*). The theory also furnished a means for planning and evaluating measurements of suspended load on streams such as those made on the Missouri River at Omaha by the U. S. Army Engineers. Ismail (*25*) used essentially the same theory to study the turbulence structure of flow in a closed channel. The important discovery by Lane and others (*29*) of the dramatic effect of water temperature on sediment discharge may also be related to the development of the suspended load equation.

General Problem of Alluvial Streams

In the early 1950's there appeared a series of papers reporting research on alluvial streams in both the laboratory and field. These represented a change in emphasis from the suspension process which dominated preceding years, and a return to the approach pioneered many years earlier by Gilbert (*21*) in the laboratory and Buckley (*10*) and others in the field. However, the new generation of workers came equipped with the knowledge in fluid mechanics developed in the several intervening decades which prepared them to clarify further the complicated problem.

In this period Einstein (*16*) published his bedload function, which applies the suspended load theory, and at the same time unites the hydraulic relations into a unified transport theory. In this work the effect of bed forms on the friction factor of an alluvial stream was accounted for explicitly by applying the relation for river channel roughness developed by Einstein and Barbarossa (*17*) from measurements on streams. Much of the value of this work lay in the fact that it pointed up the pertinent factors rather than in the relations themselves. Colby and Hembree (*14*) and others applied these relations in measuring the total sediment discharge of natural streams and in developing a relation for estimating the unmeasured load based on the Einstein bedload function and measured suspended samples. This represents a new approach, in that measured quantities such as velocity and suspended load concentration, which at best can only be estimated by present formulas, are used in theoretical expressions to estimate the unmeasured portions of the load. The resulting sediment discharge is much more reliable than one calculated from theory alone without the direct measurements. At this time also the work of Leopold and Maddock (*30*) appeared on detailed observations in streams of the variation with discharge of such quantities as sediment discharge and velocity, which served to focus attention on this interesting problem.

Laboratory studies in flumes concentrated on careful and complete observations, not only of sediment discharge, but also of friction factors, size and shape of bed forms, and their motion. Some of the contributions to this work were those of Barton and Lin (*7*), Brooks (*8*), Liu (*34*), Simons and Richardson (*43*), and Kennedy (*26*). These studies identified some bed forms not reported by Gilbert, such as the sand wave (*8*), chutes and pools (*26, 43*), and peaked antidunes (*26*), and generally refocused attention on the flow in alluvial streams as a complete system, instead of dealing predominantly with the sediment discharge, as was done in the early decades of this century. In connection with bed forms, it is pertinent to note the work of Anderson (*5*) and Kennedy (*26*) in applying classical wave theory to correlate sizes and types of bed forms instead of the Froude number alone, as done previously. The result of most far-reaching impact to come out of this flume work was that of Brooks (*8*). He demonstrated by careful experiments and reported very clearly that flow with a given depth and slope, and hence bed shear stress over a movable bed, can occur with at least two velocities. The one with the lower velocity will have a dune-covered bed, a high friction factor, and relatively low sediment discharge, and the other will have a flat bed, low friction factor, and high sediment discharge. To use Brooks's terminology, these results showed that the velocity and sediment discharge of a stream are not uniquely determined by shear stress. This tended to destroy the foundations of most sediment discharge relations that assume a unique relation between shear stress and sediment discharge.

However, a more important result of this work was the clarification of the importance of bed forms and the focusing of attention on them. By so doing, it tended to give direction to laboratory and field work much as the development of the suspended load theory had done about 15 years previously. The important work of Carey and Keller (*11*) on observation of the variation of bed forms with stage in the Lower Mississippi River, of Colby (*13*) on discontinuous rating curves, and of Dawdy (*15*) on the same subject were logical developments which drew directly or indirectly on the ideas set forth by Brooks (*8*).

While a substantial segment of the laboratory and field research of the past decade was being devoted to studying interrelations between bed forms and their effect on velocity and sediment discharge, other researchers were concerned with larger features, such as channel shape, river forms, and the characteristic meanders of alluvial streams. The work of Leopold and Maddock (*31*) on stream geometry dealt with the entire stream system. This work established that there were universal relations between the three variables of stream width, depth, and velocity and the discharge at a station, and that similar relations existed between these variables at different stations along a stream and a characteristic discharge at the station. This development was an important factor in diverting attention from details such as bed forms and focusing it on the stream system as a whole, a process that is necessary from time to time in the orderly development of a science. Other work in the general area includes that of Lane (*28*) and Leopold and Wolman (*32*) on river forms, of Leopold and coworkers (*33*), Parsons (*40*), Bagnold (*6*), and Ippen and Drinker (*24*) dealing with hydraulic resistance in curves, of Schum (*42*) on the effect of sediment-type on channel shape, and of Brush (*9*) on sediment transportation in curves.

These studies showed clearly that the resistance in curves was several times that in equivalent straight sections, and indicated that for the same shear stress the sediment discharge in a curve is severalfold less than in an equivalent straight section. These two significant findings are important not only because they contribute to the understanding of alluvial streams, but because they generate a number of specific questions which will serve to organize other researches to answer them. In this sense, this work on meanders furnished the same kind of impetus as did the development of the suspended load theory two decades ago, and the clarification of the effect of bed forms less than 10 years ago.

One activity which deserves mention in any summary is the development of measuring techniques as carried out by the Federal Inter-Agency Committee on Water Resources (*2*). The impact of this activity on all work in sedimentation, whether it be research or engineering, is very significant on a worldwide basis. The fact that good apparatus and techniques are readily available for making sedimentation measurements not only makes such measurements possible in many instances, but it tends to guarantee that they will be comparable to others, and thus admissible to the fund of general information on the subject.

Other activities, such as the important work on the design of channels, scour at structures, production of sediment from watersheds, etc., have not been mentioned only because of limited time.

Summary and Conclusions

In reviewing the research work of the last 15 years, it is clear that this has been a period of great activity and significant progress. There has been a marked increase in field research on streams over previous periods and a return to laboratory studies of flows over movable beds. There has been a very apparent close liaison between field and laboratory. This is evidenced by the fact that field studies are applying laboratory results and laboratories are pursuing studies suggested by field investigations. This liaison was brought about mainly through the literature, but also, to an important extent, through the personal contact between workers and by reason of the healthy intellectual climate that exists in this activity.

I have pointed out three developments which in my opinion have keynoted the work of recent years. These are (1) the theory of turbulent suspension, (2) the clarification of the role of bed forms, and (3) the discovery of the great difference between flow in curved and straight channels. The first of these differs from the other two in that it is expressible theoretically in equations in concise and quantitative form. As such, it is readily understandable, and can be assimilated into textbooks and preserved permanently. The other two items are qualitative ideas, expressible only in words, and hence their true significance is appreciated only by those with some familiarity with sedimentation. Because of this they are more difficult to incorporate into textbooks and are in danger of being lost and then rediscovered, as was the work of river engineers of several generations ago.

I believe that these examples serve to illustrate the importance of theory, and the urgent need for its further development in sedimentation. Theory forms a framework into which information can be fitted or filed in such a way that it is readily available. It not only tends to collect bits and pieces of information from old files by providing the filing system, but it also stimulates workers to get information needed to complete the picture that the theory was intended to portray.

The theoretical treatment of the sedimentation problem is very difficult, and will develop slowly. It will be based on the understanding gained from experiments rather than by some break-through by a stroke of theoretical genius. However, in order for the experiments to contribute understanding, they must be designed carefully to answer certain questions or to prove or disprove hypotheses based on reasoning and results of other investigations. Considering the primitive state of knowledge of sedimentation, contributions can be made in many ways. Clarification of old ideas based on published data can be of significant value and publication of data, particularly from the field, showing peculiar behavior of streams, can contribute to general progress even if the author cannot explain what he has observed. In a sense, the understanding of sedimentation, which we are all seeking, can be likened to a structure. The plans for this edifice will be the theory that we ultimately hope to develop to express our understanding of sedimentation processes but which is not yet available. The bits and pieces of information resulting from researches are the bricks for the edifice and will all fit into it in an orderly way once the plans are complete. In the meantime, they must be stored, i.e., published, or they are in danger of being lost to future builders of the sedimentation edifice.

Before concluding my remarks, I would like to say a word about the future. With the growing population and the increasing demand for water resources, it is clear that sedimentation will assume even more importance than it has in the recent past. This will generate the need for better solutions to sedimentation problems which must be based on better understanding of the basic processes of sediment movement. The population and the demand for water are exploding, while the research activities in sedimentation are only moving along at a fast walk.

Since the research results of one generation tend to become the working tools of the next, it is clear that it is urgent to accelerate the pace of research. To do this we need three things: (1) leadership, (2) money, and (3) research workers. The leadership must come from engineers and other technicians responsible for the water resources development. They are the ones that will be faced with the problems and the responsibility for their solution. It is also their responsibility to see that means are available for coping adequately with problems to come. But it is also the responsibility of the experts in the profession, as represented by this group, to call attention to the need for the added activity so that funds and facilities will be provided.

Without a competent well-trained body of research workers, the program will not progress and it will be impossible to continue its financial support. To train a research man takes several years of formal study and additional years of experience in research. A number of universities offer graduate work in fluid mechanics and sedimentation that will prepare people for research in sedimentation, although the enrollment in such programs is less than can be accommodated. The bright young man is turning his back on sedimentation and river engineering in preference to the fashionable pursuits of the space age. Without such people, we will not be able to meet our obligations in the years to come. This situation can be changed by a vigorous campaign to inform people of the important, fascinating, and challenging problems in sedimentation and of the opportunities that this field provides for careers. All of us can help in this task. We can accept invitations to talk about our work to engineering groups, clubs, and particularly to high school groups and individual high school students. We have an important, interesting, and challenging profession, but we need to let the world know about it.

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EDUCATIONAL NEEDS AND OPPORTUNITIES IN THE SEDIMENTATION FIELD

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The subject of this paper, needs and opportunities in education, cannot really be divorced either from the preceding papers by speakers of very much more experience in this field than I or from the subjects which will be discussed on subsequent days at this meeting. Nevertheless, I will try here to take a rather general look at some of the educational approaches to diverse aspects of the field of sedimentation.

My method consists of a crude demand and supply analysis, including a statement of the compass of the subject, an estimate of the practitioners, and an evaluation of the educational needs of several different groups.

Like hydrology, it seems somehow to be the custom to consider sedimentation solely as a kind of subspecies of a variety of engineering fields. This is a narrow view, however, and interest in sedimentation is actually much broader than this. Archeologists study history from depositional sequences. The interests of geologists range from surficial processes to detailed analysis of the structure and fabric of deposits. Within the broad field of engineering itself, sanitary engineering deals with sediment as a pollutant and with the ecologic effects of sediment; soil mechanics, with the mechanical behavior of sediments; civil engineering with river control, reservoir design, harbor development, and with all types of construction. Foresters are concerned with land use. Agronomists and others in land management are similarly interested in sedimentation from the standpoint of conservation of the land and increasing yields from the land.

Unlike the dictionary, which refers to sedimentation as deposition of sediment, it is clear that these varied approaches to sedimentation, indeed this conference itself, include within the subject erosion, transport, and deposition. As I will attempt to show, this threefold division, perhaps because of its very neatness, appears to have created some surprising barriers. One of the educational tasks is the destruction of such barriers.

Although the interests mentioned are quite extensive, it is much more difficult to discover the number of persons actually engaged in the field of sedimentation. The 1960 survey of scientific personnel by the National Science Foundation indicates that there are only 500 scientists in this country who consider hydrology as their first specialty. About 100 indicated a primary specialization in civil engineering aspects of waterways and harbors. Although this presumably does not include a fairly large contingent of engineers, it seems apparent that if there are so few hydrologists, the number who would consider themselves specialists in the field of sedimentation is very much smaller.

Looking, for example, at the program for this meeting, I note that there are 91 papers and abstracts. Assuming perhaps 1½ authors (it is usually the one-half author who does most of the work), we might tentatively conclude that there are perhaps 150 "sedimentationists" generally associated with the research aspects of sediment studies. The majority of these are in fact more occupied with practical problems relating to design and operation of hydraulic works than with research per se. Nevertheless, these authors represent a large segment of the professionals specializing in sedimentation.

At the opposite end of the scale it must be observed that soil conservation districts in the United States embrace more than a billion and a half acres, a vast area. In addition, hundreds of large reservoirs and thousands of smaller ones have been and are being constructed today, long sections of river channels have been canalized, and harbors cleaned of sediment. All of these activities involve problems in sedimentation. It is quite clear then that if one takes a possessive view, there must be quite a large number of professionals who are "poaching" on the field of sedimentation. Let us guess that there are several thousand so involved.

The probable population of those directly connected with engineering aspects of sedimentation might be closer to 1,500. Within the teaching profession itself, the number of professionals engaged in teaching and research in sedimentation can only be guessed. As I will show in a moment, this number must in fact be exceedingly small. Thus, I would surmise that in the field of sedimentation as a whole, we are probably talking at most about some 2,000 people in this country. (No doubt there are a larger number following various manuals in attempts to make designs for the kinds of engineering problems in which sediment enters in.) The number of true devotees must be closer to 200 to 300.

Judging from the number of geologists who selected sedimentary petrology, petrography, or recent and paleo-sedimentation as their first specialty in the manpower survey, there are perhaps an additional several hundred geologists actively pursuing interests in the field of sedimentology.

It is questionable whether one can sum these diverse interests, but as a rough estimate let us assume that there are about 1,000 professionals genuinely interested in sedimentation.

Despite some sad previous experience with attempts to analyze college courses in hydrology from either college catalogs or from the response to questionnaires sent to educators, I tried to compile some information on the status of courses in what might be called sedimentation from a sample of 30 or 40 college catalogs. Courses in civil engineering and in geology were reviewed.

Although I purposely chose the larger State universities as well as the bigger private institutions whom I supposed might include offerings in this field, confirming what most of you already know, it appears that there are perhaps 10 universities in the United States that include formal courses in their engineering schools dealing with problems of sediment transport or with the broad field of sedimentation. These are also the universities which have large hydraulic laboratories in which work in sedimentation may be pursued. Only seven perhaps have really concentrated in the field of sediment transport. This sample does not include the agricultural programs in which sediment and erosion problems are most certainly mentioned.

My review of college catalogs indicated that there are about a dozen formal courses which carry titles such as "Sediment Transport," or "Problems of Sedimentation," or "Engineering Aspects of Sediment Problems." Several universities have specific courses related to coastal engineering, rivers and harbors, or irrigation and canal design.

(I should emphasize here that throughout this review, I am not lamenting, I am simply reporting.)

Within the field of geology, there are many more courses in the broadly defined field of sedimentation. These include stratigraphy, sedimentary petrology, and sedimentology. Virtually all geology departments offer stratigraphy, less, but most, offer sedimentary petrology, but relatively few offer courses in sedimentology. Although in the general field of sedimentation, the orientation of all of these courses is toward distinguishing environmental or stratigraphic characteristics of deposits and rocks. Sedimentology comes closest to being a course in sedimentation and this course is the least common of the group.

The present status of education in sedimentation is perhaps most clearly illustrated by a brief look at some of the textbooks in the field. In the engineering aspects of the subject coverage usually consists of several chapters in general texts on hydrology or hydraulics. One of the more complete coverages, from the standpoint of subject matter included, is the chapter by Brown in the volume *Engineering Hydraulics* edited by Hunter Rouse. This volume is much in demand and I believe out of print. The chapter on sediment transport includes material on sediment yield, reservoir deposition, transport, river control, beach and harbor problems, and sediment sampling. The treatment is necessarily short but the subject matter is broad. A number of books, many quite old, do deal with river behavior, but most are rather specialized and do not emphasize principles of sedimentation.

For the geologically oriented sedimentationists, there are a variety of texts beginning with Twenhofel's *Treatise on Sedimentation* and including such excellent works as Pettijohn's *Sedimentary Rocks* and a number of other texts in stratigraphy and sedimentation, in sedimentary petrology, as well as a few in geomorphology such as the classic *Physics of Blown Sand and Desert Dunes*. Somewhere between the engineering and geologic approaches is the series of collected essays on *Applied Sedimentation* edited by Trask. All of these offer material of tremendous interest, but due to the highly specialized treatment of each, they do little toward providing a comprehensive view of the field.

Both from the standpoint of courses and texts, the present condition of education in the field of sedimentation can be characterized rather simply. First, the quantity of offerings is limited. Second, the material offered is generally fragmented or for a specialized audience appropriate to particular aspects of individual disciplines. Lastly, virtually no courses or texts are available that present a comprehensive view of principles and problems in sedimentation traversing the entire "sedimentary" cycle from erosion through transport to deposition and lithification.

Having looked very briefly then at the present state of affairs, let me consider equally briefly some specific needs and opportunities. The educational demands may be conveniently separated into four parts: (1) General education; (2) design and practice in engineering applications; (3) specialized disciplines; and (4) research.

General education in principles of sedimentation applies to a much larger audience than we are accustomed to think of. In this I include introductory courses in natural resources, conservation, ecology, and general geography. The variety of offerings are enormous, and they range in level from grade school to graduate school. Erosion and sedimentation are dealt with as aspects of land use and management. As a result of the very successful efforts begun by Hugh Bennett and others in the 30's most of these courses and texts treat the subject with warmth, if not alarm. One might say that the present need is met satisfactorily. Perhaps if anything is needed, it is a more thoughtful approach that outlines the processes involved and provides the student with a better framework than the citation of isolated catastrophic examples usually provides. In addition, some information needs updating and clarification.

(My sanguine view that saturation by conservation concepts is attained is probably too optimistic. It may be doubted, in fact, that many citizens in our large urban communities are either aware of the nature of conservation or of the concept of intelligent land use.)

The second category, education in sedimentation for those engaged in engineering enterprises has some aspects of general education in that perhaps the largest single task is to make the engineering profession, and particularly the civil engineering profession, fully aware of the significance of sediment behavior. There are still a great number of practicing engineers who are either unaware that sedimentation poses certain special problems in their field or who choose to ignore the problems of which they are aware. Relatively few texts in open channel hydraulics consider the kind of flow problems, which will be discussed at this meeting, that are related to water and sediment movement in channels with mobile boundaries. The same could be said about the treatment of a variety of other engineering aspects of sedimentation. One of the missions then for education in the field of sedimentation would seem to be that of increasing the awareness of the field on the part of all of the practitioners. It is unlikely that most engineers will need to or will be likely to become experts in sedimentation alone. However, they share a need for a comprehensive understanding of the field of sedimentation with foresters, geographers, agriculturalists, geologists, and others concerned with land and water problems.

To satisfy this demand for a comprehensive introduction to principles of sedimentation, formal courses and texts are needed that consider the entire erosion cycle pointing up the interconnection between the parts and emphasizing the unanswered problems. Hopefully, such courses would include the dynamics of erosion, the mechanics of transport by various media, and the nature of depositional environments. The amount of detail with which each subject would be covered would depend upon both the length of the course and the degree of specialization of the audience. Such a course would not necessarily be a substitute for specialized subjects such as sediment transport and canal design. It would insure a general introduction, however, both for those who will receive the specialized courses and for others. I would hope that eventually all the universities and colleges offering major programs relating to water and land use would include such a comprehensive course.

In connection with the stimulation of awareness of the principles and problems in the study of sediment, an outstanding educational need lies in disseminating information to areas now only beginning to develop their resources and economies. Here the comprehensive view is essential. Many such places in humid tropical regions, for example, will face complex sediment problems as watersheds are cleared, land developed, and dams constructed. My own travels have convinced me that as we become more sophisticated and specialized, it becomes harder for us to communicate with these areas of the world. Many have little or no access to most of the published literature in the field.

Because I consider it one of the most useful services that the United States might provide in this field, I should like to suggest that this Federal Inter-Agency Sedimentation Conference take the lead in preparing an outline and in assigning authors to portions of a general manual in the field of sedimentation. (If it didn't have the wrong connotation, I would characterize it as "a poor man's manual of sedimentation," much as many of us refer to the need for "a poor man's 888," to supplement the U.S. Geological Survey manual of stream gaging. My model would be something like the handbook, *Low Dams*, or perhaps some portions of *Low Dams* grown bigger, called "Small Dams.")

The approach of such a manual would be on the "how to decide what to do," and "how to do it" level. For this reason, it might borrow heavily from existing manuals of the Federal agencies and from the American Society of Civil Engineering manual that is in preparation, but the sedimentation manual should differ from the others in style and content. Topics covered might include sediment descriptions, alternative methods of sampling sediment in streams and principles of network design, problems of scour and fill, estimating sediment yields, sediment delivery ratios, measuring sediment in reservoirs, and erosion controls. Suggested methods in each of these topics would include the most simple techniques, as well as the usual fancy ones, and present selected data that would emphasize evaluation of the costs of alternatives, and discuss the appropriateness of certain techniques to specific regions or to specific problems at desired levels of accuracy. This might be helpful in combating the conflicting tendency encountered not infrequently; that is, precise measurement of very little at great cost in labor and equipment, or no measurement at all on the assumption that all observations must be made with complex equipment and by highly educated personnel.

Virtually all of those who could compile such a manual will attend this meeting. Perhaps a start can be made. I should guess that it could be completed in 6 months to a year. Let me turn now to the two remaining areas of education in sedimentation; specialized disciplines and research.

Physical geologists and geomorphologists are primarily concerned with landscape, with erosion and transportation of sediments, and, on occasion, with particular depositional forms. This interest in landscape and process leads to a direct concern with the broad relations between climate, erosion, and deposition, and thus also to concepts of equilibrium and climatic change in the evolution of land forms. These questions in turn are of direct consequence to professionals concerned with land management. Elsewhere within the field of geology, however, stratigraphers are concerned with the characteristics of sedimentary deposits that have become rocks. There is considerable current interest in attempts to compare modern sedimentary environments with paleo-environments, particularly efforts to understand the sedimentary conditions associated with the location of oil. Unfortunately, relatively few of those who study modern sedimentation also look at the rocks and vice versa. Here again there is a real need for a true combination in which the dynamics of modern sedimentary processes and depositional environments are analyzed and described in a comparable way such that features can be seen in the rocks and interpreted.

Such courses are undoubtedly taught in a few places, although I am not aware of many of them. Nevertheless, although there is yet a great deal to be learned, a text which approached the field from this standpoint would be useful in orienting students to the field. It would treat the mechanics of various kinds of transporting media, their sorting effects, the products derived from such processes, and environmental controls of deposition.

Much has already been said here today regarding the fourth aspect, research. It is perhaps first in importance. Because training for research is problem oriented, broad generalizations cannot be made about the kinds of education that would be appropriate unless the problem is specified. A scientist interested in the mechanics of erosion of clay may need a great deal more work in theoretical chemistry, clay mineralogy, and soil physics than will a scientist interested in some aspects of sediment transport. Although many unanswered questions in the field of sedimentation remain, well-trained people will not be attracted to the field unless these challenges are brought to their attention. Similarly, as Professor Mason noted at the first Federal Inter-Agency Sedimentation Conference, potential supporters of research must be made aware of the gaps in knowledge and of the need for research. This is a common responsibility. It requires an admission that all is not known. Further, it is up to the educators to stimulate the interest of their students in the unknowns. Research not only provides a means of teaching, but it also enhances this consciousness of the unknown and thus the needs of education are also those of research. The Federal agencies can do much to create an awareness of research needs in Congress and with the public at large, although this will require an occasional admission that all the answers are not known.

In summary, then, it would be a mistake to assume that because many of us gathered here share an intense common interest, that vast numbers of experts in the field of sedimentation will be required in the future. In this category alone, I should place the total between 200 and 400 individuals at most.

Additions and replacements in this group, perhaps 10 to 20 per year, will require concerted efforts — not because the number is large but because today the competition for all kinds of scientific personnel is stiff.

Judicious emphasis on, and support of, research should stimulate university interest and serve to attract students to the field. Numerically, a larger task of education would appear to be in broadening the understanding of sediment problems among engineers and others dealing with land and water. These two complimentary objectives will require some increase in faculty qualified to teach principles and problems in sedimentation. Hopefully, more of those now being trained to such competence will remain in the teaching profession and will not be wholly absorbed by engineering firms in which their specialized interest is little used.

In a word, we need a comprehensive view, we need courses which expound that view and textbooks that facilitate such courses. And to keep the field vital, we need strong research efforts to ask questions and hopefully to answer some.

Lastly, there is an educational responsibility to disseminate what we have learned to a wider audience. Not necessarily because we know a great deal more but at least in part because we have been able to afford a wide range of experience, experience which has included howling success and occasional dismal failures. Both should be reported.

Hopefully, this has not been entirely platitudes but has given you something to feed on.