Pipes

REPORT ON THE
SECOND NATIONAL CONFERENCE ON

Environmental and Sanitary Engineering Graduate Education

Sponsored by the
ENVIRONMENTAL ENGINEERING
INTERSOCIETY BOARD
and the
AMERICAN ASSOCIATION OF PROFESSORS
IN SANITARY ENGINEERING

Held at
Northwestern University
Evanston, Illinois
August 27–30, 1967

REPORT OF THE SECOND NATIONAL CONFERENCE ON ENVIRONMENTAL AND SANITARY ENGINEERING GRADUATE EDUCATION

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PREFACE

Eight years have passed since the June 1960 Study Conference on the Graduate Education of Sanitary Engineers. During that interval a number of significant changes have occurred that make it appropriate for the profession to reexamine its educational objectives and resources. Indicative of the expanding role of the sanitary engineer, in 1964 the American Sanitary Engineering Intersociety Board (ASEIB) adopted a new name, the Environmental Engineering Intersociety Board (EEIB). The changing role of the sanitary engineer in the federal establishment was recognized when the functions of water pollution management were transferred from the Public Health Service to the Department of Interior's Federal Water Pollution Control Administration. Perhaps more important, yet less tangible, has been the growing public concern for all aspects of environmental pollution and the increasing awareness among engineers, particularly those from civil engineering, of their rather special responsibilities for the environment. It was because of this concern and its meaning to our educational programs that the American Association of Professors in Sanitary Engineering (AAPSE) was organized in December of 1963. This awareness was also the reason for the preparation in 1966 of a new Register of Graduate Programs in the Field of Sanitary Engineering Education as a joint effort by AAPSE and EEIB to bring the earlier register up to date.

The objectives of the Second National Conference on Environmental and Sanitary Engineering Graduate Education are best summarized in the Table of Contents, where the nine Task Committee titles are listed. It is evident that environmental engineering is an interdisciplinary science based on the engineering and applied science fields for which man and his well-being are the principal focus. Although his is not the only profession concerned with the environment, the sanitary engineer, through his several decades of involvement in the management of water, air, food, and environmental pollutants, has certainly established his position in the environmental fields. It is noteworthy that the accomplishments and leadership of the sanitary engineer during this period led to the elimination or control of many communicable diseases rampant at the turn of the century. It is appropriate and timely that the sanitary engineer and his science colleagues examine this position vis-a-vis the needs of the nation, the probable nature of its future development, and the adequacy and requirements of the educational programs serving environmental engineering. This was the broad purpose of the 1967 Conference at Northwestern University.

ORGANIZATION OF THE CONFERENCE AND REPORT

The Conference was jointly sponsored by the Environmental Engineering Intersociety Board and the American Association of Professors in Sanitary Engineering. A nine-man Steering Committee was appointed by these two organizations, and Professor G. A. Rohlich of the University of Wisconsin was elected Chairman and Professor W. J. Kaufman of the University of California, Vice-Chairman. The Steering Committee membership was comprised of representatives from the two sponsoring organizations and included individuals from the fields of chemistry and biology.

Nine study topics were selected and nine Task Committees appointed. One member of the Steering Committee served as a liaison member on each of the Task Committees as well as moderator of that Committee's session at the Conference. Each Committee was encouraged to meet before the Conference. Draft versions of each Committee's report were distributed at the Conference and summary reports were presented at each of ten sessions, two sessions of which were devoted to the subject of graduate curricula for professional and research careers in environmental engineering.

Attendance at the Conference was open to all individuals concerned with education, research, and practice in the broad field of environmental engineering. Invitations were sent to more than two hundred persons located in educational institutions, in federal, state, and local government, and in consulting engineering firms and industry. Among the invited were those listed in the 1966 register as well as those in attendance at the 1960 Conference.

The Task Committee reports and discussion from the floor provided the material for the preparation of the final report by the Editorial Committee: Professor G. A. Rohlich, Professor W. J. Kaufman, Dean H. B. Gotaas, and Dean L. G. Rich. The Steering Committee was authorized by a formal motion of the Conference to prepare the final report and to express in it the consensus of those in attendance at the Conference. The Steering Committee has taken this charge literally and has been liberal in its editing of the original reports. In some instances new data have been introduced by the Committees, while in others the Editorial Committee has materially changed the organization and terminology of the Committee reports in order to achieve greater coherence and a more logical overall structure. The nine chapters of the report have been ordered somewhat differently than the Conference sessions; thus, the session and chapter numbers do not correspond.

The first two chapters deal with the roles and activities of personnel in environmental engineering and include the input from committees whose members have a great diversity of functions within the field today. Chapters III through VI deal with the *disciplines* which impinge in a determinative way on environmental engineering; chemistry, biology, the social sciences, and systems analysis. Chapters VII and VIII are concerned with certain special educational problems of the field—the essential role and education of the applied scientist and the accreditation of professional graduate programs. Finally, Chapter IX establishes some guidelines for curricula in environmental engineering aimed at providing both direction and flexibility. The Report includes no final conclusions as such, although many conclusions and recommendations appear in the various chapters. However, a summary of the final session has been included as Appendix A in order that the record be complete with regard to formal resolutions made at the Conference.

Prior to publication, copies of the final report were made available for review to all Steering Committee members and to the Task Committee Chairmen. At a meeting of the Editorial Committee in August 1968 the comments of these individuals and their committees were considered and further changes made in the report. It thus should be emphasized that this Report of the Second National Conference on Environmental and Sanitary Engineering Graduate Education represents the efforts of a great many individuals, the majority of which will substantially agree with the final results.

ACKNOWLEDGEMENTS

Financial support for the travel of the Task and Steering Committees as well as for expenses for conducting the Conference and preparing the final report came from two sources. A grant was provided by the National Science Foundation, through the Division of Graduate Education in Science, and was administered by Northwestern University, with Dean H. B. Gotaas as principal investigator (NSF Grant No. G2-424). A second grant was provided by the National Center for Urban and Industrial Health, Public Health Service (Grant No. UI-00394-01) to the American Association of Professors in Sanitary Engineering, with Professor W. J. Kaufman as principal investigator. The Conference Steering Committee wishes to acknowledge gratefully this assistance, without which the Conference and this report would not have been possible. The Committee also wishes to thank Northwestern University and the faculty and staff in environmental engineering and especially Professors W. O. Pipes, E. R. Herman, J. E. Quon, H. Cember, and H. B. Gotaas for their assistance and for the excellent facilities made available by Northwestern for the Conference.

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I. THE ROLE OF THE ENGINEER IN ENVIRONMENTAL ENGINEERING

Webster defines environment as "the aggregate of all the external conditions and influences affecting the life and development of an organism." If we identify our organism of principal concern to be man, the definition is suitable and explicit and we need only to specify the nature of the engineer's involvement. Here the definition of environmental engineering provided by the Environmental Engineering Intersociety Board will serve admirably:

> "The term *Environmental Engineering* means the application of engineering principles and practices to one or more elements of the environment for the purpose of protecting or improving man's health and well-being. It includes the control of the air, land and water resources, man's personal and working environment in relation to his health, social and economic well-being, and the design and maintenance of systems to support life in alien and hostile environments."

The title of this Conference—*Environmental and Sanitary Engineering Graduate Education*—raises the question of the meaning of sanitary engineering as distinct from environmental engineering. As will be seen later in the report, the term environmental engineering has replaced sanitary engineering as a more appropriate expression of the breadth of the field, while the latter term has become the designation of the professional in water quality management. Today the practicing sanitary engineer is principally concerned with the planning, design, construction, operation, and regulation of water quality control systems as primarily related to water supply and purification, sewage collection and treatment, and the evaluation of the effects of urban drainage on quality. To a lesser extent, the sanitary engineer today is also involved with the broader aspects of water resources, air pollution control, solid residue control, urban planning, and general sanitation. While most of the sanitary engineers are associated with water-oriented projects, there are those who have become concerned with air pollution control, industrial hygiene, and solid wastes disposal. The sanitary engineering professors in a majority of the universities are largely engaged in the teaching of water quality oriented courses, and the direction of their research is to this same area.

It is recognized that the preceding statements do not fit the environmental concept of the sanitary-civil engineer. It appears that an evolutionary trend has developed, pushing sanitary engineering into the water quality specialty. Certainly few can argue with the philosophy that a sound approach to engineering education requires that a sanitary engineer become a specialist before he is qualified to become a generalist in the sense implied by the term environmental engineering.

Whereas the traditional concept of sanitary engineering, as stated in the various National Research Council (NRC) Committee Reports, assigns him a broader role than water quality management, today the generic term *environmental engineering* has assumed the meaning of the historical designation *sanitary engineering*. The latter term has become the species designation for water quality management. It is not likely that a single individual can fulfill all the requirements of an environmental engineer and represent himself as such. This circumstance has been recognized by EEIB and the American Academy of Environmental Engineers. The new certificates issued to diplomates of the Academy will carry only one of four specialty designations:

Sanitary Engineering
Industrial Hygiene Engineering
Air Pollution Control Engineering
Radiation and Hazard Control Engineering

HISTORICAL COMMENTARY

The education of sanitary engineers has had a long and honorable history when compared with post-graduate education in many other branches of engineering. The record is supported by the following simple statistics: Of every 100 engineers practicing in the United States today, approximately 20 are in civil engineering, and of these one is a sanitary engineer. Among all the engineers practicing, about 25 percent have post-graduate degrees. However, among the civil engineers, fewer than 20 percent have completed any post-graduate study; whereas, among sanitary engineers, almost 80 percent have earned the M.S. or Ph.D. Degrees. This record of post-graduate education of sanitary engineers is exceeded only by a very small group of nuclear engineers (data from *Engineering Manpower in Profile*, Engineers Joint Council, 1964).

The standing of any profession stems in good part from the educational qualifications of its practitioners. Sanitary engineers have long been advocates of post-graduate education. For this reason, as well as perhaps their greater involvement in social developments, many sanitary engineering professors in the past have been selected to serve as heads of departments and as deans of engineering schools in numbers far exceeding their representation in academic institutions. Furthermore, virtually all of the major educational institutions that offer post-graduate study in engineering in the United States have a program in sanitary engineering.

Much of this record of accomplishment can be attributed to such giants in sanitary engineering education as Gordon M. Fair at Harvard and others. Their writings, their leadership, and their precepts have done much to give stature to post-graduate sanitary engineering education in the United States. For many years it was sufficient for educators to follow the examples set at the leading institutions in establishing their own directions. As the profession grew, however, the need for the formalization of educational policy became apparent.

The NRC Conference Report

The NRC conference owed much to the leadership of Abel Wolman, then chairman of the Committee on Sanitary Engineering and Environment, and to Professor Earnest Boyce, then chairman of the Subcommittee on Personnel and Training. The conference was sponsored by the Public Health Service, and it is not inappropriate here to point out that the profession owes a considerable debt to the sanitary engineers of the Public Health Service who did so much to assure support for sanitary engineering education. The roster of others who played significant roles at this conference is long and distinguished.

The 1957 conference affirmed the definition of the term *sanitary engineer* as developed by NRC in 1943 and revised in 1954. An important recommendation of the conference was a five-year program involving a four-year undergraduate civil engineering curriculum followed by professional specialization in the fifth year leading to the master's degree. The conference concluded that the four-year undergraduate specialization in sanitary engineering failed to supply enough sanitary engineering graduates to meet the demand. It also concluded that options in civil engineering curricula were frequently deficient in the basic sciences of chemistry and biology. Therefore, they recommended against separate undergraduate degree programs in sanitary engineering and against professional specialization in undergraduate civil engineering curricula.

The 1957 conference, recognizing the role of the sanitary engineer at that time in health agencies, recommended a one-year program leading to the master's degree with about 25 percent of the time being devoted to *core* courses including environmental hygiene, engineering statistics, and epidemiology. The electives were to depend upon the area of specialization within sanitary engineering: (a) public health, (b) water works and waste disposal works, (c) industrial hygiene, (d) radiological health, and (e) air pollution control. It was recognized that while graduates of a civil engineering curriculum would be better qualified for post-graduate study in specialties related to public works, graduates from mechanical and chemical engineering might be better qualified to pursue graduate study in other specialty areas such as air pollution or industrial hygiene. Although mention was made of the education of physicists, chemists, and biologists, no special graduate program was outlined for them other than indication that in order to obtain an engineering degree they should be required to take the engineering prerequisites.

It was not contemplated that any single educational institution would be in a position to offer programs in all of the specialty fields of sanitary engineering, but many schools would have programs in at least one of the fields.

The conference devoted considerable attention to career opportunities in sanitary engineering but gave major attention to recruitment and recruitment incentives. Included among the recommendations were the expansion and extension of traineeship and fellowship programs, particularly in the specialized fields of sanitary engineering at the post-graduate level.

The Harvard Conference

In 1960 sanitary engineering education was on the threshold of major expansion in the United States, as evidenced by the sharp increase in research and training grants at educational institutions and the concomitant growth in faculty and graduate enrollment (cf. *Register of Graduate Programs in the Field of Sanitary Engineering Education*, sponsored by the American Association of Professors in Sanitary Engineering and the Environmental Engineering Intersociety Board, June 1966). The American Sanitary Engineering Intersociety Board (predecessor of EEIB) sponsored a study conference on the graduate education of sanitary engineers at Harvard University on June 27–29, 1960, under a grant from the National Science Foundation. Thomas R. Camp, formerly professor of sanitary engineering at M.I.T. and then chairman of the Board of Trustees of ASEIB, was conference chairman. Available to the conferees was the first sanitary engineering education directory, prepared by Professor Gilbert H. Dunstan of Washington State University.

Major attention at the conference was given to graduate curricula in the fields of (a) water resources engineering; (b) air resources engineering; and (c) public health engineering, with special attention also given to the basic science courses incorporated in these curricula.

Among the conclusions of the 1960 conference was the statement that sanitary engineering education should be expected to play an increasing role in preparing engineers for careers concerned with water resources. For the first time it was emphasized that competence in the field would often require education to the doctoral level with a wide variety of programs being necessary to meet the needs in these broad areas. In programs of study in water resources it was thought desirable to have additional course work in hydrology, hydraulics, and systems analysis.

In the discussion of the field of air resources engineering at the Harvard conference, it was concluded that terms *air hygiene* and *industrial hygiene* engineering were more suitable. Incorporated in the report was the recognition that radiological hygiene engineering also would be a specialized field closely related to air hygiene and industrial hygiene and more distantly related to water resources engineering.

In considering the sanitary engineer in the general field of public health engineering, courses from a wide variety of subject areas were suggested for inclusion in the curriculum by the Harvard conference, much as laid out in the 1957 NRC conference report. Somewhat more emphasis was to be placed on subjects in public administration, political science, planning, and economics. It was evident that among the five designated *specialty* fields, public health engineering was the field for the gereralist.

A conference committee devoted to biology and chemistry requirements for master's degree programs in sanitary engineering elucidated specifically what the course content should be.

In reviewing the work of this conference, it appeared evident for the first time that a wide variety of program areas and course curricula were branching from sanitary engineering. The conference did not try to prescribe rigid requirements or any single program of study, but it did indicate opportunities for expansion into areas of educational opportunity that were on the horizon. This inevitably led to considerations of terminology problems and the conference recommended that ASEIB undertake a study of this matter. (One result of this recommendation, together with pressures within the profession itself, was the adoption by ASEIB of its new designation: Environmental Engineering Intersociety Board. Environmental engineering was intended to include all fields of activity formerly incorporated in the NRC definition, with individual fields of activity, including that of sanitary engineering, covered by this *umbrella.*)

Another major concern of the conference was the accreditation of post-graduate programs in sanitary engineering beginning at the level of degree programs. It recognized that to be accredited it would be unnecessary for an educational institution to offer instruction in more than one of the fields designated by the conference. The conference recognized ECPD as the organization best suited to administer the accreditation program.

Among other specific recommendations of the Harvard conference were the following:

1. The minimum length of time for graduate instruction leading to the first degree in sanitary engineering (i.e., in water resources engineering, air resources engineering, and public health engineering), or the master's degree, should be one calendar year rather than one academic year.
2. All of the program areas, including water resources engineering, air resources engineering, and public health engineering should have a common core of chemistry, microbiology, radiological hygiene, statistics, and epidemiology.
3. It became apparent that some formalized collaboration between educational institutions involved in sanitary engineering education would be desirable, and accordingly the conference requested that ASEIB refer to its Committee on Education the question of the desirability of initiating formal collaboration.

The Airlie House Conference on Educational Needs in Environmental Health

At the instigation of the Public Health Service and under a contract with the National Academy of Sciences National Research Council, an invited conference of 24 educators and other interested professional persons was held at Airlie House for the purpose of developing ways of meeting the increasing need for personnel for teaching, research, and practice in environmental health. Several of those participating were involved in the previous conferences and were in attendance at this one, notably Professor Gerard Rohlich. In addition, however, there were present specialists from other fields related to environmental health, including medicine, agriculture, health physics, meteorology, physiology, and toxicology.

The following were major recommendations from this conference:

1. There should be established interdisciplinary environmental health research centers at selected universities. In the instances where a single university could not adequately provide the resources for the field of environmental health several institutions should cooperate.
2. A considerable increase in the number of, and amounts of money for, institutional grants for environmental health research training and facilities should be made.
3. The fellowship program should be expanded and some means provided for supporting undergraduates preparing themselves for careers in environmental health.

More ECPD-Accredited Curricula," *J. Engineering Education*, **56**, December 1965.)

It is noteworthy that prior to about 1959 or 1960 the increase in master's degrees in water quality (or, for all practical purposes, in sanitary engineering) was only 3 percent per year compared with the average for all fields of 11 percent. However, in the 1960–1965 period, the growth increased to double the average, presumably as a consequence of increased need and of federal, state, and industry subvention.

ROLE OF ENVIRONMENTAL ENGINEERS IN CONSULTING PRACTICE

The term *consulting engineering* is assumed to mean the provision of expert assistance to clients (public and private) for developing solutions to problems through studies, design, or special investigations and research. Consulting engineering is actually practiced by an extremely small proportion of the total engineering profession, and quite often within a consulting firm only the principals and a limited number of key staff members actually practice consulting. It is necessary to realize that the concept of the environmental engineer whose role in the profession we are trying to establish is limited to those engineers having sufficient background and training to qualify as experts in a specialty area of environmental engineering (as distinguished from those who might be classified as *straight* civil engineers).

An environmental engineer's role in the consulting profession is that of solving real problems in a real world for real clients upon whom he must depend for real money. This is not meant to discredit the academic world or those with responsibilities in governmental agencies; but it is important to note that success in consulting work requires an appreciation of reality probably to a significantly higher degree than in other pursuits open to the engineer. A limited budget imposes stiff requirements for efficient work; for planning and making periodic evaluations to insure that schedules are being met; for communicating periodically with the client to be certain that the product will be *receivable*; and for considering all pertinent factors, including the physical, economic, political, and aesthetic, which if neglected might result in voiding an otherwise good product.

The environmental engineer's work assignment may be oriented toward true consulting (i.e., advising) or toward actually performing a service such as data collection and analysis, research, process development, process engineering, detailed engineering (i.e., preparing construction drawings and specifications), project representation during construction, operation manual preparation and operator training, feasibility studies (technical and economic), rate studies, planning studies, systems analyses, environmental criteria studies, and resources management. The individual engineer may play the role of a specialty consultant, an administrator, a project manager, a project scientist or engineer, a technical supervisor, a research technician, a process development technician, a process engineer, a detailed design engineer (i.e., one who selects equipment, arranges piping and structures, and concerns himself with many other project details including costs), a representative on construction, an operations problem specialist, a specialist on pollution causes and effects, a system analyst, a resources manager, etc. He frequently plays the role of coordinator; he coordinates the efforts of planners, chemists, biologists, hydrologists, meteorologists, geologists, other scientists, lawyers, financial experts, and other engineers. This is one of his more important roles.

Present Role

Design accounts for almost two-thirds of the consultant's total present activity, and within the design category the design of waste disposal or water pollution control works is more common than the design of water supplies.

There is a definite trend toward greater activity in making studies and preparing reports and special investigations. Report preparation will probably become increasingly important in the consulting business. Due to the accelerating technology characteristic of the times, problems facing the profession are becoming increasingly more complex and therefore require much more thought and study before an action program of preparing plans and engaging in construction can be initiated. It may be said that environmental engineering practice is gradually changing from its past nature, wherein the solutions to problems were generally developed by selecting and applying fairly standardized methods or systems on an essentially empirical basis, to a much more scientific activity involving a careful appraisal of the basic facts which are being made available through research. The design activities of consulting firms show a trend toward more activity in the preparation of plans for water pollution and water quality control facilities with a corresponding decrease in the proportion of time spent on design activities concerned with water supply facilities. This trend is no doubt due primarily to the increase in concern of the federal government over the past decade regarding the maintenance of the quality of water resources.

Research activities within consulting firms are increasing. The data on research activities show that two-thirds of this effort is directed toward problems of wastewater management. Again, the reason for this emphasis may be the acute concern for these problems that has been shown by the federal government.

There is a current shortage of expert engineers, particularly qualified sanitary engineers, created by the rapid increase in the numbers of technological problems that exist. However, the role of the consulting profession becomes even more difficult to perform when this shortage of technically qualified individuals is amplified by an even more severe shortage of people who are cognizant of and capable of performing in a realistic manner tasks requiring such non-technical considerations as client relations, effective expression in speaking and writing, management, and appreciation of the importance of political and economic considerations.

Future Role

There are two definite trends in the role of the environmental engineer in consulting work: (a) a trend toward increased activity in all phases of the profession, and (b) a trend within the profession that shows increasing activities in studies, report preparation, and special investigation including research. Water pollution control and water quality management have become increasingly important in recent years because it has become obvious that the available water resources must be considered to meet the needs of continuing growth and development. The acute awareness of this problem has created the changes occurring today and is the basis for the trends that seem to be developing. Reclamation of wastewater (of interest in arid areas) also adds impetus to the trend toward increased activities in wastewater and water quality management. Probably the most important single factor stimulating the further development of sanitary engineering in the water resources field is growing recognition that problems of water pollution control (to preserve environmental values) and of water conservation (to meet the needs of growth) will often be found in reclamation and reuse. The problems faced by the consulting engineer in this area are challenging and demanding. As the development of technology progresses, the melding together of the technical skills involved in traditional water supply engineering and water quality-wastewater engineering are inevitable.

It appears that the future role of the environmental engineer in the consulting profession will be one in which he will be required to cope with comprehensive and complex problems that combine at once all the aspects of water quality-wastewater management, water supply, solid waste disposal, urban planning and air pollution. As he acquires experience, the engineer-consultant will be required to be less of a specialist; and yet the paradox is that he will, at the same time, be required to be more technically competent due to the complexities of the problems he must resolve. More of his efforts will be directed toward making studies, preparing reports, and participation in research. This trend, however, will probably not minimize the relative importance of the design functions he must perform. The future role will also require a more acute awareness of the many interactions with the surrounding environment that will occur, due to the large and complex nature of the problems involved. Skill in management techniques will also become more important due to the magnitude of the problems and the need for coordination of the efforts of different professional disciplines. And it must be emphasized that the role within the confines of the consulting business will require a realistic knowledge of the functions, regulations, and funding of governmental agencies. Without this capability even the most technically competent may fail.

Future Educational Requirements

Certain deficiencies in the capability of today's environmental engineer in the consulting business are apparent. In view of the role he will play in the future, certain additional adjustments must be made in his educational program if he is to cope with his problems effectively. It is believed that most of the following suggestions for alteration of existing graduate curricula will benefit the consulting environmental engineer in either his present or future role.

The first conclusion is that any young engineer who aspires to a key or leading role in his career should have a minimum of a master's degree and preferably a doctor's degree. The age of accelerating technology means simply that in every walk of modern life the doctorate level of education is becoming a requirement for professional stature for all but those few brilliant enough to succeed without advanced preparation.

From the standpoint of the consulting engineering profession, doctoral programs in environmental engineering should emphasize a rigorous technical preparation in the basic and applied sciences to establish a foundation for competence in technical thinking. In addition, an effort should be made to prepare the student in several areas:

1. To be competent in expression—in writing and speaking. This does not mean just a casual course in reports (taught by another engineer not particularly interested nor expert in this role) but a rigorous course which transcends engineering and focuses on fundamentals of writing as a means of expression.
2. To be aware of the importance of other disciplines in the practice of engineering, including management, economics, sociology, urban and

regional planning, and social and political science.

3. To be aware that design is important as the *core* of engineering practice and that only in design can concepts be realized. This means recognition by the academic profession itself of the role of design and provision in curricula for imparting design principles to the student.
4. To be sure that the environmental engineer has a full understanding of systems analysis and all approaches to the application and coordination of the physical, biological, economic, social, and political sciences pertinent to achieving optimum solutions to problems.

ROLE OF THE ENVIRONMENTAL ENGINEER IN THE FEDERAL ESTABLISHMENT

In describing the role of the environmental engineer in the federal government, it may be well to address the discussion at the outset to the federal role in environmental engineering. The burgeoning technical developments, with their follow-on problems, have had very substantial impact on the several departments of government which have environmental involvements. The reactions have ranged from the establishment of defined programs which deal with one or more environmental medium (and whose genesis may in some cases be traced back to the turn of the century) to the exhibition of a great deal of uncertainty as to what the next step should be.

Over the past several years, one or another segment of government has conducted studies intended to describe the metes and bounds of the problems to be faced in achieving a high degree of environmental quality. These studies have examined the nature and scope of the efforts required to carry the quality control task forward and have also examined the respective roles of government, industry, and the academic sectors. From these studies a consensus may be derived, although not stated as such. Four principal work areas are identified or implied which in total represent a monumental task. These are: (a) the establishment of quality standards for the environment, (b) the establishment of an overview or surveillance system to determine standings with respect to these standards, (c) the creation of a mechanism to trigger corrective action when undesirable encroachments are recognized, and (d) the identification of a lead agency to coordinate national efforts in the field.

It is quite obvious that these tasks will be performed well only if they involve the scientific and technical capabilities of the country. How then should they be divided? And of the involved agencies in government, which should carry the lead or primary responsibilities? Such a federal agency should direct its efforts to the problems and their size, participate in the formulation of program and fiscal policy, plan and direct the federal programs, plan for manpower resources, and manage the needed extramural programs. The nature of this federal role and the extent and nature of nonfederal involvements will vary, depending upon where in government the responsibilities reside. This is obvious because of the differences in the orientation and basic mission of the several departments. For example, an agency committed to the support of the educational process, the support of research, the utilization of the resources of the scientific community at large, and the operation of a variety of extramural programs in the pursuit of national objectives would operate environmental programs within its purview in a different manner than would one committed to defense or to resource development. Important too is the question of the nature of the determinants for action: Are they based on health or aesthetics or economics, or do we know enough yet to say? Clearly this is a matter to be resolved at the highest levels of our government.

The role of the engineer in the environmental field has an extensive background. Despite the opinions of some, it is likely that the role of the environmental engineer will continue to be dominant. This is because engineering is a common thread in the multidisciplinary fabric that is required, and the environmental engineer's basic training in civil engineering, with its extension into one or more fields such as chemistry, biology, physics, or other areas important to the life sciences, provides him with the needed scientific and technical backgrounds. He thus is afforded the opportunity for total comprehension of the problem and the needed programs. That is not to say that change is not needed, for his future role will depend upon the quality of his background and its orientation to the problems of today and the future. The public health emphasis given to the field in the recent past is still important, but other education must be provided. To better fit the sanitary engineer for his special input into the environmental quality management role (economics, business administration, management technology, etc.), the research role (which in general could be more relevant, rather than building upon old edifices), and for design purposes (stressing innovation, the application of research, and practice), concentration in one of these areas should be provided for as well as in the subspecialties of his field. A look, too, at the academic degree-granting function may be desirable, particularly the midcareer types of training leading to professional degrees. The latter might provide an excellent linkage between academia and the practitioner, the programmer, or the policy maker.

These linkages will be important, for the nature of the interface between the educational institutions and the environmental engineer in the federal establishment will have much to do with the activities of and the product of engineering schools.

THE ROLE OF THE ENVIRONMENTAL ENGINEER IN INDUSTRY

At this time data are not available which will lead to a conclusive statement relative to the role of environmental engineers in industry. It is recognized that a number of civil-sanitary engineers, usually after receiving additional specialized training, are employed by industry in waste treatment, air pollution control, industrial hygiene, and radiological health. This number has been small because most of the undergraduate and graduate education prior to the last decade in civil-sanitary engineering was directed to public works and public health engineering.

Today it is recognized that a larger number of professionals receiving graduate degrees in environmental engineering have undergraduate degrees in areas other than civil engineering, particularly in chemical and mechanical engineering.

The interest that industry has in the specialist educated in air or water quality management is growing. This interest becomes very apparent when one studies the number of job offers made by industry to the present graduates of specialized environmental engineering programs. Until a detailed and long range study is made, it will be impossible to predict the role of environmental engineering in air and water quality management in industry. Certainly the environmental engineer's input to solving industry's in-plant and community-related problems will continue to grow, but he must be prepared to compete with the chemical and mechanical engineers.

ROLE OF THE ENVIRONMENTAL ENGINEER IN INTERNATIONAL AGENCIES

Among the international agencies using significant numbers of environmental engineers are the United Nations (its natural resources—economic, social, and educational components), the World Health Organization, the Agency for International Development, the World and Regional Development Banks, and the foundations. In the developing countries themselves there is great variation in the utilization of environmental engineers. Some of the African and Asian nations have practically none. Others, like the major Latin-American countries, are in their second generation of sanitary-water resources engineers. They use them extensively and are now training significant numbers of civil-sanitary engineers, mostly at the undergraduate level but increasingly at the master's and occasionally the doctoral level.

Perhaps the perplexing aspect of the international scene with respect to the developing-country/sanitary engineering picture is the need to span the spectrum from basic sanitation to the most involved analysis and planning for the engineering components of very large-scale developments. Where major river basins, for example, are to be the subject of comprehensive and integrated planning and development, the sanitary-water resources engineer must be prepared to provide his contribution along with those of other professionals. Some dependence can be placed on external consultation, but this is not a satisfactory continuing substitute for developing indigenous competence.

Of special significance is the effect of graduate education on the role of the environmental engineer in developing countries. Because of the health significance of environmental engineering and its public domain aspects, it came to be supported at the graduate level by foundations and international assistance programs (IIAA, TCA, AID, WHO, UNESCO, UNDP, etc.), often earlier and generally to a greater extent proportionately than other branches of engineering. This educational advantage is showing up markedly in the number of graduate environmental engineers who are occupying positions of responsibility as national, state, and municipal heads of public works, water supply, sewerage, air and water pollution, industrial hygiene, and public health engineering organizations. Moreover, they are being placed in these positions at an earlier age than is normal in developed countries. Therefore, since they have not had as many years to accumulate through experience the basic preparation for planning, administration, and management, it is more important that they have some such preparation in their graudate education. This poses the double-headed dilemma of providing both professional engineering preparation and basic engineer-administrator preparation in some practical combination within some feasible time schedule. It raises a question regarding the merit of science-oriented doctoral programs for such individuals.

ROLE OF ENVIRONMENTAL ENGINEERS IN THE STATE AND LOCAL HEALTH DEPARTMENTS

For many years some environmental engineers have worked with physicians and others to control communicable diseases caused by bacterial invasions. The fact that many of these invasions are the result of contaminated air, water, etc., makes it the proper concern of engineers. Engineering activities have been typified by the advances made in municipal water supply, in the disposal of solid and liquid wastes, and in similar functions. These engineers have been employed by state and local health agencies to perform the role of government in regulating through the promulgation of standards and other means and to insure a quality of food and water that is acceptably safe for the consuming public. The regulatory function has been primarily exercised by units of health agencies in the past. The utility service function has usually been performed by other agencies, sometimes established as a utility and sometimes just performed as a government service. Industrial hygiene and radiological health are areas where the role of the environmental engineer at state and local levels has been primarily one of performing a regulatory function rather than providing a utility type of service.

With the growing popular concern for air pollution, the old smoke abatement programs have taken on new emphasis as we have become aware of chemical pollutants in the air as well as the particulate matter and other products of combustion. As the emphasis shifted from concern only with combustion to concern with chemical processes and other sources of pollution, the environmental engineers who had been involved in industrial hygiene problems expanded their interests to include air pollution.

What do engineers who work with the environment do when they are employed by state and local governmental agencies? Most frequently there is an investigative function that involves the identification of problems through field visitation, engineering surveys, sampling, and the taking of other measurements to evaluate environmental conditions. These investigations may relate to water treatment plants, wastewater treatment facilities, manufacturing processes that would create safety or industrial hygiene problems, various operations that contribute to air pollution, the facilities which emit ionizing radiation, food handling and processing establishments, and the like. If there is a regulatory power, it becomes necessary for these individuals to institute action to enforce conformity to official standards. Usually, the official agency charged with responsibility does not consider its job to be complete at this point. Many, in fact most, of these agencies believe that they have an educational function to perform. Such a function can involve education of the public as to the nature and scope of the problem, and it may include the training of operating personnel and others who by their actions can prevent many problems from arising. Because of concern for pollution of the environment, rather than making heroic efforts to curb pollution after it has occurred, agencies may require that new installations be constructed in accordance with standards. This may require a plan review function for evaluating the proposed installation to determine if it will serve its intended function. Some agencies feel it is their duty at this point to give advice concerning the types of approaches that have been successful in the kind of situation under consideration. However, most governmental agencies are careful to avoid involvement in the selection of specific equipment or in the actual design of any particular installation. Where a plan review function is performed, it is necessary for the government engineer to be capable of evaluating the design proposed, and thus he should have had design experience. Some of the more advanced state and local units feel that it is desirable for their units to go beyond the activities indicated and to perform research and studies to find better solutions to problems confronting the jurisdiction in which they work.

One area in which the environmental engineer has been remiss in responding to public need is that of housing and urban development. In many instances, the engineer in the health unit responsible for environment has under his supervision the maintenance of minimum housing standards. These standards frequently relate to the supply of water, plumbing, disposal of wastewater, handling of refuse, and other conditions deemed to affect the health of the housing occupant. While some consideration has been given to the inhabitants' psychological needs, such as freedom from excessive noise and vibration, little attention has been given to the determination of the basic sociological and psychological criteria for housing and for the residential community. There have been, of course, some standards for minimum occupancy of housing. However, most cities are considered to have large areas of housing which are overcrowded by generally accepted criteria. The criteria in use today, however, have little basis in scientific fact, and research needs to be performed to establish rationally these human needs in the urban community.

In many state agencies and the local agencies serving large populations, the engineer responsible for the quality of the environment will supervise extensive staffs composed of many disciplines. The growing problem of urbanization will lead the sanitary engineer into closer association with such professionals as economists, political scientists, lawyers, and communications engineers, and he will be faced with the organization and administration of government services necessary to bring these diverse competencies to bear on the problem of environmental health.

Educational Requirements

State and local agencies, consequently, need two types of engineers for environmental activities. One will be the professional engineer who can evaluate and formulate technical solutions to resolve specific problems. He must have the capacity to design adequate and safe engineering works (or to review the designs of others) to prevent or to correct environmental problems. The second kind of professional will be more of an engineer-administrator or planner. This position will require leadership in developing a total approach to the planning of an urban industrial community that is a fit place to live. The individuals in these positions must participate in community decision making. They should understand not only the technical aspect of environmental problems but also be aware of and understand the political, social, and economic aspects.

These requirements of state and local agencies have important implications for graduate education. It is obvious that the "reason for being" of an environmental engineer is the technical expertise he brings to the solution of problems. Consequently, any educational plan should have a strong base in science and engineering principles. The time schedules imposed in most master's degree programs suggests that the student should concentrate in one of the areas of environmental concern, e.g., water supply and water pollution, air pollution, radiological health, solid waste technology, industrial hygiene, etc. However, to fulfill his responsibility in state and local government, even the specialist must understand the interrelationships between his field and the other aspects of the environment. Here again we see the dilemma of the educator, the conflict of depth in a specialty versus breadth and knowledge of the related disciplines.

Inasmuch as the master's degree is a terminal professional degree for most engineers in government, it is necessary to provide for those students who have aspirations in this direction a breadth of education that will enable the student to understand and to cope with the political, social, and economic factors associated with the implementation of engineering solutions. Many solutions of technical validity have proved unacceptable when subjected to these other measures of merit. The engineer will be a leader in formulation of government policy only to the extent to which he is able to relate to a total approach encompassing engineering and the physcial, life, and social sciences.

It is obviously impossible to offer a single one-year educational program that both creates a technically competent specialist and a leader-generalist. Here we believe there are several alternate solutions that will serve students of different ages, technical proficiencies, and interests. For the recent baccalaureate primed in the science and technology of engineering, a specialized master's degree in water or air resources would best prepare him for service in both public and private organizations. For the middle bracket engineer-supervisor, perhaps in his mid-thirties, a different and much broader curriculum would be appropriate to prepare him for further advancement in public health. Here a sort of engineering equivalent of the MPH might be appropriate, but with liberal exposure to systems analysis, public administration, water resources, and regional and city planning, along with courses that would provide some up-dating in his technical specialty. This approach should not preclude the young man from an early start in administration, but in this instance he should be encouraged to enter a graduate program in public administration in a college other than engineering. A third alternative is, of course, the doctorate, preferably one focusing on professional practice and breadth rather than on the scientific aspects of a particular problem.

CONCLUSIONS

1. Sanitary engineering, as practiced today, has evolved from the roles of engineers in public works and public health agencies and in consulting engineering firms. While the field has increased in breadth to a degree that the generic designation "environmental engineering" has been adopted, it has also increased in technical complexity such that the present-day sanitary engineer is, for all practical purposes, a *water quality engineer.* Only the more senior administrators oversee the environmental field, which is experiencing a heavy influx of water, air, radiological, and other specialists from all the scientific disciplines as well as from engineering and the social sciences. It is becoming increasingly evident that other engineers, especially the chemical engineer, will have ever more significant roles in all fields of environmental engineering, especially in the sanitary-water quality management field and in air pollution control.
2. The role of the engineering educator is to prepare engineers and scientists for careers in environmental engineering and science. The engineers must be capable of resolving today's crises and of recognizing tomorrow's problems. Some, in fact the majority of the engineers, should be educated as specialists by curricula strong in the discipline of science yet focusing on the real world of engineering such that the student is made aware of his role as a doer. Several curricula will be needed to meet these objectives,

and great care should be exercised in designing these to treat the real rather than the imagined and to serve the needs of the student rather than the interests of the professor. Here the advice of the practitioner should be sought and taken. We should avoid the ephemeral and the expedient, while seeking the innovative and the new. The educator is also a researcher, and through his research he also educates the doctoral student. Here an effective compromise must be found between the educator's often very specialized interests and the student's career in engineering.

3. The environmental engineer has a role in industry. As a water quality or sanitary engineer he must be prepared to cope with industry's specialized needs for process water and for wastewater disposal facilities, and he must acquire these capabilities with the aid of educational programs that take cognizance of his early academic background in one of the several fields of engineering, especially chemical and civil. As an air pollution or industrial hygiene specialist he must be prepared in the sciences and advanced technologies pertinent to the practicing of these professions. Finally, some engineers in industry will aspire to administrative roles, and if successful will function across the broad spectrum of environmental engineering.
4. The civil-sanitary engineer is the principal consultant to municipalities, and this important interface with public works and urban development should not be overlooked in our educational planning. Although here the major problems in the environmental engineer's realm of competence will remain largely with water and wastewater or sanitary engineering, great opportunities exist in the broader areas of planning and administration as well as in the air resources specialty. It is believed that profitable joint educational ventures should be developed with other fields of civil engineering, particularly those of transportation and building design, with the purpose of creating the urban environmental engineer, i.e., the municipal engineer.
5. The present role of the environmental engineer in consulting engineering, especially one having a civil engineering background, is primarily that of a sanitary engineer who investigates water and wastewater problems and who prepares the reports and facility designs comprising these solutions. To some extent in recent years the sanitary engineering consultant's role has expanded to encompass the broader area of environmental engineering, and without doubt opportunities are developing in the solid waste, air pollution, and urban planning fields. It is believed that a trend exists toward increased activity in report preparation and research, especially in the waste management fields (air, water, solid), but design and supervision of construction remains as the most remunerative aspect of consulting. A common criticism of academic programs is their lack of emphasis on the tasks of the consultant, especially report preparation and design.
6. Considerable confusion exists with regard to the differences and similarities of the terms *sanitary engineering*, *environmental engineering*, and *water resources engineering*. It has been established by EEIB and proposed herein that environmental engineering be a generic term which includes sanitary engineering and that this latter term implies principally water quality engineering. Here we should emphasize that sanitary engineering, like public health engineering, will continue to connote the breadth of environmental engineering, but this situation should not deter us from more precise definitions where they are necessary for clear communication. Water resources engineering has come to have a generic significance somewhat akin to environmental engineering but restricted to the water sector of the environment. The principal engineering participants in water resources are the hydraulic engineer-hydrologist and the sanitary-water quality engineer. Implied also in the term *water resources* are a vast array of physical, biological, and social science disciplines that impinge on all socio-technical problems of our society. Clearly, systems analysis is playing an ever-increasing role in water resources, as it is in resolving all major environmental problems, but it should be viewed more as one of the disciplines than the field itself.
7. Environmental engineers who are employed by public health agencies may be expected to practice their profession in greater breadth at an earlier age, especially in the lower echelons of government. The engineer in the lower echelons of government most frequently becomes engaged in investigative functions that involve the identification of public problems through field visitation, engineering surveys, sampling, and the taking of other measurements to evaluate the environmental conditions. These investigations may relate to water treatment plants, wastewater treatment facilities, solid waste disposal operations, manufacturing processes that would create safety or industrial hygiene problems, various operations that contribute to air pollution, the facilities which emit ionizing radiation, food handling and processing establishments, and the like.

In the international sector, especially at the policy-making levels, a high degree of maturity and breadth of scientific, engineering, and intellectual strength are important requisites to the practice of environmental engineering.

Consequently, engineering students who hope to work for health agencies may find it desirable to take course work in public administration, epidemiology air pollution control, vector control, solid waste management, and municipal finance.

II. SCOPE OF ENVIRONMENTAL ENGINEERING

Over the past decade such traditional fields as those dealing with water supply, water pollution control, industrial hygiene, radiation safety, housing hygiene, vector control, good protection, air pollution control, and solid wastes disposal have experienced great expansion. To these must now be added such new areas as urban environmental health planning, regional development, transportation, injury prevention, and closed environmental systems. An overriding concern is resulting from recognition of the interrelatedness of the elements of man's environment. It becomes ever more apparent that successful, effective management of that environment depends upon a keener understanding and an accomodation to this interrelatedness.

The engineer conducts activities for the improvement, control and management of man's environment for his health and well-being. The scope, magnitude, and complexity of these activities has broadened immeasurably over the past few years. Improvement in engineering practices, particularly over the past decade or two, enables the engineer to do a much better job of planning and conducting research and development activities. Society's growing awareness of the importance of effective environmental quality management has intensified his action programs. The nature of such programs has had great impact not only on his technical activities but on his economic, behavioral, social and legal activities as well. His ever-growing use of sophisticated systems analysis techniques makes it possible for him to compare alternate strategies with respect to relative costs and effectiveness.

Expansion in the number of areas of concern is more than matched by the greatly enlarged scope of activities now being conducted by the environmental engineer. Problem identification and quantification; design and operation of environmental surveillance systems; establishment of environmental quality standards; design, development, and application of control systems represent some of the activities carried out in the public and private sectors of our domestic economy as well as in universities and international agencies.

Traditional research, training, and program operation activities have become exceedingly complex. The environmental engineer has carried out his activities as a member of a multidisciplinary team on which chemists, biologists, microbiologists and physicians were members. His graduate education enabled him to communicate with his team members and to work effectively with them. The tremendous growth of environmental health problems and the demands of society for their elucidation and control have had great impact on activities carried out by the environmental engineer. More and more he has become the manager of the environment. He has greatly expanded his team and his activities. The opinion was expressed that the environmental engineer must be able to work effectively as a member of a multidisciplinary team assigned to solve a specific health problem. The question was asked: Is he fitted by his training to be the leader of such a team? His training should, in fact, enable him to make a unique contribution to the team, because he would bring to the team a comprehensive understanding of the problem. This might then give him special qualifications to become the team leader. However, it was thought that factors of personality, intelligence, and drive would determine the team's leader, not his professional qualifications. It was felt that the environmental engineer should seek to do what he is best qualified to do. He should in this sense be satisfied to be a specialist on the team.

Computer science, information systems, systems analysis, operations analysis, and simulation models have become essential to the environmental engineer in the conduct of his activities. The nature and complexity of these activities together with the increasingly important role that society itself must play in attaining and preserving a healthful environment explain the social activities in which the environmental engineer finds himself ever more deeply involved.

The activities of environmental engineers include:

1. Anticipation of the probable effects of proposed actions specifically designed to modify man's living environment, evaluation of proposed urban and regional development plans in terms of man's health, and perception of the possible effects of programs of environmental change which in themselves are not directly related to man's health.
2. The planning, organization and conduct of programs dealing with fundamental relationships between the phases of the environment and man's physical and emotional health. These activities require the engineer to be involved in decision-making processes at all levels and to work with a variety of practitioners from other professional fields, not only physical and biological scientists, but social scientists, lawyers, political scientists, and planners as well.
3. Management of programs including cost-effectiveness analysis, economics and the budgeting process, and the employment of systems analysis in developing optimally balanced programs. Discussion at the conference stressed the point that the environmental engineer should be familiar with program management processes. This includes knowledge of: (a) decision-making processes as a vital

phase in acceptance of a program; (b) systems analysis in the design of optimally-balanced programs; (c) budgeting process at federal, state and local levels; and (d) legislative processes including steps in the preparation and handling of desirable legislation. Further, it was brought out that these processes can be made tangible and meaningful through use of the internship mechanism, that is, through work experience in urban areas planned as part of the educational process.

4. Study of land use, urban rehabilitation and urban planning, all of which have grown in importance in their relationship to the quality of environment and man's health. In addition to the ongoing activities in these areas of concern, the environmental engineer must be active in the design and conduct of studies proposed for so called demonstration or experimental cities. In this regard, it was suggested that the environmental engineer should determine what his special role should be with respect to urban environmental problems involving social and psychological stresses. Does he accept a responsibility in this area of health protection? In this connection, the recommendations in the Linton Committee Report concerning the role of the ecologist were described. A question was implied in the discussion: Is the ecologist a new breed of environmental health worker, or is this term synonymous with the environmental engineer's concept of his own role in health protection?
5. Deepened recognition of the interrelationship of environmental media such as air, water, land. This multiphased environment and the integrated, simultaneous impact of all environmental stresses upon man's health, have led the engineer to a constantly increasing use of systems analysis for determination of an optimum procedure for achieving a desired quality of environment.

This brief review of activities is intended to point toward the problems of the future rather than the past; our educational objectives must look forward rather than backward. We recognize that decision time spans have been greatly narrowed, that modern communications media have heightened public awareness, that new management knowledge and techniques have come into being, and that technological innovations are developing constantly. The view was expressed that formal educational programs should motivate the student to make the educational process a continuing one, in fact, a life-long one. Beyond the fundamentals, programs should be felxible and designed to enable the graduate to adapt readily and efficiently to a wide spectrum of career opportunities. It was stated that research experience could be valuable beyond the immediate objective of the research in that it would enable the graduate to deal with challenges more effectively.

While all these factors affect our academic programs for environmental engineers, the plight of the practicing professionals presents a different picture. A critical challenge to environmental engineering educators is presented by the need to design and conduct educational activities that will bring and keep practicing professionals abreast of the times.

Discussion during the Conference brought forth sharp differences regarding the meaning of the term *environmental engineering* and whether this was a branch of engineering in the sense that electrical or civil or sanitary engineering are branches. As noted elsewhere in this report, in the final session of the Conference it was agreed that environmental engineering was a generic term covering the specialty area of sanitary engineering as well as the engineering aspects of air, industrial hygiene, and radiation management. However, during the final session the Conference also accepted the following definition:

> "Environmental engineering is that branch of engineering that involves the application of scientific principles to the prevention, control and management of environmental factors that may influence the physical and emotional health of man and his well-being."

Rather than attempt to resolve what may be only a question of semantics, it is evident from the report of the Committee on Scope of Environmental Engineering that whether a branch, a field, or a universe, environmental engineering is interdisciplinary in character and concerned with all of the problems faced by man in an industrialized society. Although the concept of environmental engineering may have had its origin in public health engineering, it is becoming ever more apparent that our public health organizations are far too limited an institutional base from which to manage the environment of the future. The recently enlarged functions of the Department of the Interior and the establishment of the Department of Housing and Urban Development are clear evidence of our growing national concern for the quality of man's environment. Its effective management must involve the services of many of the traditional engineering professions as well as the social, biological, and physical sciences.

III. CHEMISTRY IN ENVIRONMENTAL ENGINEERING CURRICULA

In attempting to identify the chemistry needs of environmental engineering curricula at the graduate level, one must first ask the nature and purpose of these curricula and the origin and backgrounds of the entering students. In the closing session of the Conference four principal specialty areas were agreed upon: (a) sanitary engineering, (b) industrial hygiene engineering, (c) air pollution control engineering, and (d) radiation and hazard control engineering. At the master's level it is reasonable to assume that graduate education is to be structured such that individuals of diverse backgrounds will be given the tools to practice professionally within each specialty. Although the sanitary engineering designation will probably continue to carry the implication of breadth in environmental management, it is also evident that this term applies specifically to individuals concerned with water and wastewater quality and perhaps to those in solid waste management. Moreover, in many organizations the term *public health engineer* will also continue to designate the broadly concerned engineer-administrator responsible in varying degrees for all aspects of environmental management, from rural sanitation and vector control to water supply development and hospital design. Further, recognizing that curricula in various schools have evolved to meet local needs or the requirements of some portion of the national problem, it is evident that no single formula can be devised to design the chemistry courses of all graduate programs. Rather, these must be established on an individual basis.

Several additional problems should be recognized before one attempts to set forth the particulars of the chemistry courses for environmental engineering curricula. A majority of the students entering the sanitary engineering curriculum are civil engineering graduates with only freshman level preparation in chemistry generally completed four to six or more years earlier. Clearly, these students are not prepared for graduate-level courses in chemistry, but rather should receive as their first course one designed to overcome their deficiencies and to meet their specific engineering needs. There is a question as to who should teach the chemistry courses—a chemist on the environmental engineering faculty or a sanitary engineer with a doctoral minor in chemistry; or whether suitable courses in the chemistry department be sought. Ideally the teacher should probably be a chemist in the environmental program and particularly one cognizant of the engineer's needs. Practically, this question must be resolved within the limitations and resources available at each institution.

In an effort to place some reasonable limits on its assignment, the Committee on Chemistry directed its attention to the chemistry needs for three degree situations: (a) the master's degree in environmental engineering for the individual principally interested in water and with a background in civil engineering; (b) the master's degree in environmental chemistry where the undergraduate's background was in chemistry; and (c) the doctoral degree in engineering for the student from engineering with a major interest and dissertation problem concerned with chemistry.

The Committee recognized wide degrees of variability of freshman chemistry courses but assumed that the graduate civil engineer would have had a minimum of six semester hours of freshman chemistry. This should be a prerequisite for entering the first chemistry course in the graduate program. More than six semester hours of chemistry at the undergraduate level would, of course, be highly desirable but not a practical requirement under today's circumstances. The candidate may also have had some exposure to chemical calculations in senior or concurrent graduate courses concerned with process theory and design.

MASTER'S CURRICULA IN ENVIRONMENTAL ENGINEERING

It was agreed that the principal teaching goal of the introductory chemistry course which should be taken by engineers in all of the master's level environmental engineering curricula was the understanding of the fundamental concepts of chemical theory. It was believed that most of the chemistry offered in our present programs fails to meet this goal and that considerable upgrading is needed. In setting forth the guidelines for an introductory course, the Committee recognized that the primary orientation was toward water and wastewater problems, but it also noted that the chemical principles of aqueous systems apply to all areas of the environment including the air. Chemistry courses beyond the initial course may focus on the specific interests of individual institutions and may, for example, deal with atmospheric or air process chemistry in situations where a curriculum in air pollution control is offered. A general outline of the introductory *principles* course is given in Table IV.

The heart of the introductory course is equilibria and kinetics or essentially physical chemistry. The course should be of at least three semester hours and designed for civil engineering graduates with no chemistry beyond their freshman year. It should not

TABLE IV
PRINCIPLES OF WATER AND WASTE CHEMISTRY
(3 semester hours)

A. REVIEW OF CHEMISTRY FUNDAMENTALS
   Molecular Structure
   Nature of Bonding
   Radioactive Decay
   Chemical Combinations
   Stoichiometry
   Calculations
   Units of Expression

B. CHEMICAL THERMODYNAMICS
   Heat of Reaction and Enthalpy Changes
   Entropy
   Free Energy Function and Equilibria
   Fugacity and Activity

C. CHEMICAL EQUILIBRIA
   Phase Equilibria
   Solution Theory
   Reaction Equilibria
   Ionic Equilibria
   Electrochemistry

D. KINETICS
   Reaction Orders
   Theory of Reaction Rate
   Mechanisms

E. SURFACE AND COLLOID CHEMISTRY

be taken by graduates in chemical engineering or chemistry.

The Committee suggested that a second course of at least three semester hours be offered dealing with the application of concepts of chemistry to water and wastewater treatment or to air resources, depending on the nature of the master's curriculum. The general content of this course is shown in Table V. Such a course is as much process engineering as it is the applications of chemistry. Thus, in a first-class academic program where the engineering staff is adequately versed in the unit operations and processes of water and wastewater treatment, essentially all of the topics listed in Table V would be presented by the engineering faculty following preparation in the fundamentals by the faculty chemist. On the other hand, recognizing that the faculty chemist in an environmental engineering program is an applied scientist and thus in many respects concerned with engineering, it would seem quite appropriate for such a course to be offered jointly by several faculty and be designated a unit process course.

Such topics as disinfection and biodegradation involve biological and engineering principles as well as water chemistry, and the student should undoubtedly be exposed to some fundamental biology before studying the application of biological principles to such systems. Here also, the student should probably have received some preparation in organic and biochemistry. The Committee on Chemistry recommended that these subjects be included in the biology and process engineering courses, noting that in sufficient time was available in master's curriculum to offer formal course work in both physical and organic-biochemistry. The Committee assumed that seven semester hours was the limit available for chemistry. Another possible approach that would allow the inclusion of organic chemistry and some biochemistry would be to follow the three-semester-hour introductory course with two or three hours of organic-biochemistry and parallel these with one or two hours of laboratory, for a total of seven semester hours. In this scheme the applied chemistry course (cf. Table V) would be presented as an engineering oriented process course and could be a joint effort of chemists and sanitary engineers.

TABLE V
CONCEPTS OF CHEMISTRY APPLIED TO WATER AND WASTE PROCESSES*
(3 semester hours)

Coagulation, Softening, and Precipitation
Absorption
Ion Exchange
Membrane Techniques
Distillation
Chemical Oxidation
Disinfection
Corrosion Control
Aerobic Biodegradation
Anaerobic Biodegradation

*This course could be designated as Process Engineering or Unit Processes and Operations.

The third course offering in the chemistry sequence for the master's level of environmental engineering should be concerned with laboratory demonstrations of the chemical concepts and principles. It should require one or two semester hours, either in a single course or in a two-course sequence, and should place emphasis on the elucidation of the principles discussed in the lecture courses. The Committee emphasized that the laboratory should not consist of training in the performance of routine tests as it is not the purpose to prepare engineers as analytical specialists or laboratory technicians. On the other hand, much chemistry can be taught during the performance of the standard analyses, providing proper instruction is offered in conjunction with the laboratory.

The proposed seven semester hours of chemistry comprises about 25 percent of the one-year (two-semester) master's program in one of the specialty areas of environmental engineering. The courses described are principally for the sanitary engineer concerned with water quality, and obviously some changes would be required for curricula in air pollution control or industrial hygiene. Of the seven semester hours, it was the consensus that three should be devoted mainly to the principles of physical chemistry and that one or two should be given to laboratory work. The remaining two or three hours might be used for an introductory course in organic and biochemistry, or, as originally proposed by the Committee, for a course in applications of chemical concepts and principles or what might better be termed process engineering. Seven semester hours of chemistry is small indeed; therefore, it would probably be preferable to offer a two-hour course in organic chemistry and biochemistry and leave to the engineering portion of the curriculum the problem of process applications of chemistry.

DOCTORAL CURRICULA IN ENVIRONMENTAL ENGINEERING

At the doctoral level of education in water, air, or industrial hygiene, more than ample opportunity is afforded for preparation in depth in chemistry and chemical engineering. Generally the student entering the engineering doctoral program has completed the master's program in sanitary engineering (or in air pollution control engineering) or may hold the baccalaureate and master's degrees in chemical engineering. For these students, and particularly for the civil-sanitary engineer choosing a chemistry-oriented dissertation, a 9- to 12-semester-hour chemistry minor taken in the chemistry or other appropriate department would be desirable. Such a minor, coupled with a similar sequence of courses in chemical engineering, will lead to chemical process research of a truly doctoral caliber. The chemistry courses might include selections from surface and colloid chemistry, chemical thermodynamics, physical chemistry, organic and biochemistry, and radiochemistry.

At this juncture one might question why an individual who is basically a civil engineer would choose to specialize at the doctoral level in a chemistry-oriented aspect of water and waste water treatment or in the chemistry of natural systems. In reply we might observe that even at the doctoral level the civil engineer choosing to become a specialist in process theory and development will have been exposed, as proposed above, to no more formal chemistry and process course work than the typical B.S. graduate in chemical engineering. He has become a process specialist only in the context of water and wastewater engineering. Another answer might be even simplier; if the engineer wishes to make a contribution to the application of chemistry, he must be prepared in depth in the relevant fundamentals of chemistry. The same would undoubtedly be true in biology or the mechanics of fluids.

MASTER'S CURRICULA IN ENVIRONMENTAL CHEMISTRY

It is generally agreed that a role exists for the formally educated chemist in the environmental *sciences* as represented by the four professional specialty areas noted earlier. Thus, the principal function of a graduate curriculum in environmental chemistry should be to bridge the gap between chemistry theory and chemistry applications in engineering processes and systems. In order to further the chemistry education of students entering this program, the Committee recommended that nine semester hours of course work be completed from one or more of five advanced chemistry subject areas: (a) advanced analytical chemistry, (b) surface and colloid chemistry, (c) advanced physical or advanced inorganic chemistry, (d) advanced organic or biochemistry, and (e) radiochemistry. The remainder of the curriculum should permit the chemist to become familiar with the engineering and biological aspects of his chosen area of the environmental sciences (e.g., air, water, etc.). This could also include such diverse subjects as fluid mechanics, computer sciences, epidemiology, and perhaps even water pollution and public health administration, the choice depending on his interests and the subjects available at his institution.

CONCLUSION

The Committee on Chemistry emphasizes that environmental engineering and science programs at different institutions will have different objectives and must accommodate their courses in chemistry to these objectives and to the local constraints of departmental organization, budget, personnel, etc. It is believed that every effort should be made to utilize chemistry department offerings but that, where the situation permits, it will also be desirable to develop some capability in chemistry within the environmental engineering and science program. Without question, the environmental engineer should receive substantial formal instruction in chemistry during his initial graduate year and this should be further developed at the doctoral level where his interest and dissertation impinge on chemical sciences.

IV. BIOLOGY IN ENVIRONMENTAL ENGINEERING CURRICULA

The objective of environmental and sanitary engineering is to perpetuate or create environmental optima for maintaining human health and social and economic well-being and, in doing so, to protect the quality of our natural resources. In order to accomplish this it is essential that detrimental distortions of the environment be controlled, reduced, or eliminated. Thus the environmental engineer is required to understand complex ecological interrelationships. It is noteworthy that only when environmental distortions interact with the living systems are they of significance to man. They must be examined within the context of the biosphere, and in order to be properly equipped for an understanding of his extensive role, the engineer needs to be familiar with, and have an understanding of, biological forms and functions ranging in complexity from the submicroscopic up to man himself, as well as the interactions of living systems with their environments.

The objectives of this report are: (a) to indicate what a student aspiring to the master's degree in one of the specialty areas of environmental engineering should know about biology so as to have some degree of understanding of living organisms and an awareness of their importance in nature and in environmental engineering processes, and (b) to discuss how biologists may be educated in such a program in order to provide highly qualified scientists, with an understanding of environmental engineering problems and practices, for defining and developing an understanding of biological processes important in this field.

EDUCATION OF ENVIRONMENTAL ENGINEERS

Engineers in graduate environmental engineering programs leading to the master's degree should receive sufficient education in biology to provide them with an understanding of the basic concepts and a working knowledge of biology. This may be best achieved within a framework of ecology, because study of this broad field can serve as a unifying or integrating approach for the engineer. The ecological approach to biology, emphasizing environmental biology, offers more utility than an approach based entirely on holistic or molecular biology. The need for education in biology is recognized in considering the activities of the environmental engineer, e.g., identification of environmental problems, organization and implementation of surveillance programs, evaluation of environmental quality standards, etc. The depth of education in biology should be sufficient to meet this need. Recognizing the role of biologists in the field, engineers should have adequate knowledge of biology to communicate effectively with biologists and to make possible the team approach to solving environmental problems.

The problem of providing a program of study in the biological sciences that will equip engineers for work in the several areas of environmental engineering remains one of conflict between the limits of time in a one-year master's program and the increasing complexity of the problems to be resolved. It is highly desirable for those students who continue their studies for the doctorate to obtain more education in biology, especially when their dissertations and other interests impinge on biology. This is best achieved through the completion of a substantial minor of course work taken in a biology department.

In the case of biology, as well as in chemistry, undergraduate preparation continues to be inadequate to allow for rapid development in the more specialized areas that would help the engineer with his applied problems. In accepting the challenge to develop a cirriculum at the master's level for the engineer, the subdivisions of biology that are generally recognized as essential to an understanding of biological principles have been reclassified into the major essential components. These divisions are: (a) the nature of living organisms, (b) ecology, (c) biochemistry and molecular biology, and (d) public health microbiology.

It should be stressed that whenever and wherever possible the quantitative aspects of biology should be emphasized in order to integrate biological principles into the mathematical models used in engineering analysis and design.

Biology in the Master's Programs

The major problem with the biological portion of graduate education in environmental engineering in the past has not been that the sanitary engineer did not learn any biology, but that he often did not realize how little he had learned. As a practical matter, the time available in a one-year master's degree program for biology is usually 10 to 20 percent of the total course work (two courses out of ten to fifteen). With this time limitation, the engineer cannot expect to become a proficient biologist. The objective of biology in the engineering curricula is to give the engineer an introduction to biological terminology and an awareness of biological concepts and methodology, so that he can understand the biological literature and make the most of his associations with biologists.

Recognizing the time and content constraints, the committee agreed that biological education for environmental engineers should consist of a core course in biology common to all programs and a second course emphasizing biology but concerned with the student's area of specialization, i.e., air, water, industrial hygiene, etc.

The core course should be designed with several considerations in mind. It should emphasize principles having direct application in the several areas of environmental engineering and should use specific examples drawn from these areas. On the other hand, it should stress the specialty area of the student in programs concerned entirely with a single specialty. It should cover biology broadly enough to serve as a basis for additional courses in several of the major subdivisions of the biological sciences. Because many schools will have the basic course organized and taught in an engineering department, it should be sufficiently different from other biology courses and sufficiently advanced to be accepted by a graduate school curriculum committee. This may be achieved by placing greater than normal emphasis on the analytical or quantitative aspects and to make use of the mathematical methods in which the engineering student is prepared.

The second biology course in the master's curricula would probably be selected from the following, according to the student's field of specialization: (a) biology of unit processes, (b) biology associated with water quality and pollution, (c) public health microbiology, and (d) applied physiology and toxicology. In most schools the biology of unit processes will probably be taught by an engineer, with emphasis on the process kinetics and biochemistry rather than on biology *per se,* but the other courses on the list will most likely be taught by a biologist. It should again be emphasized that this two-course plan is a bare minimum and that all graduate students in environmental engineering master's programs should be encouraged to take additional biology courses as electives.

Within the one-year program of study leading to the master's degree, the biology to be presented in the core course will require at least three semester credit hours to enable the student to proceed along the directions indicated. The content of such a course should include the following:

CORE COURSE IN BIOLOGY

I. *The Cell*
  A. Morphological Characteristics and Organization
  B. Cellular Organization
    1. Colonies
    2. Metazoans
      a. Organ systems
      b. Specialized structures
    3. Taxonomic relationships
  C. Biochemical Evolution of the Cell
  D. Biochemical Functions
    1. Enzymes
    2. Energy sources and transformations
      a. Heterotrophy
        (1) Aerobic
          Pathways of fat, protein and carbohydrate oxidation
        (2) Anaerobic
          Hydrolysis, alcohol and acid fermentations, methane fermentation
      b. Autotrophy
        (1) Chemosynthetic
        (2) Photosynthetic
    3. Conservation and transfer of energy in biological systems
  E. Molecular Biology

II. *Ecology—Interaction of Organisms and Their Environment*
  A. Concept of Ecosystem
    1. Trophic structures
    2. Biogeochemical cycles, C, N, P, S
      a. Role of microorganisms and relationships to organic degradation
    3. Food chains
      a. Energy exchange and flow in ecosystems
      b. Productivity
        (1) Physical limits
        (2) Biological limits
    4. Kinetics of synthesis and growth
  B. Freshwater, Marine, and Terrestrial Habitats
  C. Public Health Biology
    1. Diseases of man, water and food pathogens
    2. Clean and polluted water biology
    3. Aerobiology
      a. Pathogenic microorganisms
      b. Allergins
      c. Toxic materials

The degree of emphasis or development of particular topics will depend upon the orientation and availability of the subsequent courses in the suggested pattern of development in environmental biology. If, for example, strong courses in the biology of natural systems were available on campus, time given to this subject in the core course could be minimized, but not eliminated because those students limited to the two-course sequence might not have the oppotrunity for further biology. If the biology core course were to be the only *environmental biology* in a master's program, then it should be developed into a five- or six-semester-credit-hour course.

For the engineer with little or no prior education in biology, it is important that the core course introduce him to the living materials that he will need to deal with and understand. Laboratories and laboratory exercises could best be organized in two phases, the first associated with the study of the cell and cellular organizations and the second with the presentations in ecology. The time allocations to the two divisions of the core course are suggested to be approximately 60 percent to Part I, The Cell, and 40 percent to Part II, Ecology. However, this ratio could very well be reversed, depending upon the courses subsequently offered and the particular emphasis of the specific department. The proportion of the course effort devoted to laboratory might be two lectures and one laboratory per week for a three-semester-hour course or three lectures and one laboratory for a four hour course.

The above discussion of course work in biology is most particularly directed toward the sanitary engineer and has the traditional emphasis on study relating to the aquatic environment. It should be recognized, however, that it is possible to indicate the significance of biology in other areas, such as air resources engineering and solid waste disposal, by making specific reference to these areas while, at the same time, discussing the fundamentals of biology. Depending upon the particular nature of the environmental engineering graduate program, the direction of both the core and other course material might be related more closely to the needs of students oriented toward air resources engineering or solid waste disposal.

The mechanics of offering the core course in biology will depend upon the administrative structure of the university as well as the instructional talent and resources available. There are several possibilities. The course may be offered by: (a) a graduate biologist having a background in environmental science and serving as a member of the faculty in an engineering department, (b) a biologist with or without a background in the environmental sciences and located in a biology department, and (c) an engineer having a background in biology through formal preparation in biology in a doctoral program. Whichever mechanism is appropriate to the university, it is desirable that there be an articulation of biological concepts with the area of specialization of the graduate program. In the final analysis it is desirable that the core biology course be presented by a biologist active in both his own discipline and in the environmental sciences. This is also true for the second course in biology, although here the biologist and engineer might collaborate to present such subjects as water pollution biology or the kinetics of biological systems. As many of these topics may also be discussed in treatment process or pollution control courses, it is important that close liaison be maintained between the engineer and biologist faculty members. Auditing each other's courses can prove useful and even enlightening.

Biology in the Doctoral Programs

Although the Committee on Biology did not consider the specific question of biological science for engineering students pursuing doctoral programs in environmental engineering, this matter was discussed at the Conference, and it seems appropriate to consider it briefly in this report. At the doctoral level the engineer has two reasons for seeking further preparation in the life sciences. First, he may wish to acquire a breadth and depth of understanding of biological systems beyond that possible, for example, in the proposed two-course sequence suggested for the master's program. Second, he may need additional biology to conduct his dissertation research at a level and in a manner commensurate with the work of biologists on parallel problems. This is especially true if the thesis deals with a biological treatment process or with some biological aspect of stream or lake pollution. It cannot be overemphasized that the application of biology to engineering systems by the engineer requires that he know the biological sciences on which his system depends and that he appreciate the modern techniques of handling biological material.

It is believed that this additional background in biology is best obtained through course work in one or more of the life science departments and, if at all possible, through a formal minor. Here it should be recognized that the engineer may be venturing into a foreign territory, and his lack of background may create a problem. Good counsel, especially by a biologist on the environmental engineering staff, and reasonable requirements can overcome much of this difficulty. Here it is best that the *minor* requirements be established and administered within engineering.

EDUCATION OF BIOLOGISTS IN ENVIRONMENTAL ENGINEERING PROGRAMS

Because of their potential for contributing to the solution of environmental engineering problems, qualified biologists should be encouraged to enter the field. The education of biologists within environmental engineering graduate programs is of relatively recent origin. For this reason, suggested guidelines for such education are of particular importance. It is assumed first of all that a biologist beginning such a program will have, or will develop soon after entrance, a sufficient background in mathematics and chemistry to enable the taking of such engineering and chemistry courses as are necessary for his comprehension of the engineering concepts of his area of interest. It is desirable that the program for biologists afford them the opportunity of obtaining an engineering degree or a degree in applied science which gives notice to their capabilities as specialists in one of the areas of the environmental sciences. However, the biologist can make a greater contribution to applied biology by remaining a biologist, while at the same time increasing his knowledge by further course work in both his basic discipline as well as in those disciplines related to his chosen specialty within environmental engineering.

The relative value of a degree from an engineering department as compared to that from a life science department is difficult to assess without identifying the circumstances. If the terminal degree is to be the master's, the engineering or applied science degree may offer some advantage to the B.S. biology student desiring a career in the water and wastewater engineering field. On the other hand, if an individual aspires to the doctorate and wishes to be recognized as a biological scientist, there should be little doubt of the advantage of an association with an established life science department and a Ph.D. from that department. The preparation for the non-engineering student seeking an engineering degree is discussed in Chapter VII, and these comments generally apply to biologists.

The greatest emphasis in training biologists in environmental science still should be placed on developing the individual into a more proficient biologist, and the bulk of his formal training should be directed toward this end. The majority of such course work will probably be in the areas of ecology, limnology, and microbiology with emphasis on areas pertaining to the individual's research interest. Much of this course work must of necessity be taken in one of the life science departments.

BIOLOGY FOR UNDERGRADUATE ENGINEERING STUDENTS

Because of the critical nature of the problems which the nation is facing, graduate environmental engineering programs are now attracting students with undergraduate education in many different engineering fields. Also, the developments in the fields of biomedical engineering and industrial microbiology are attracting engineers into these areas of applied biology. Thus, engineering schools should recognize the desirability of having biology courses in undergraduate curricula or at least make available elective units by which the undergraduate could satisfy this interest. The engineering student who has completed one or more basic biology course as an undergraduate could progress more rapidly in the master's program and take additional course work in biology or other areas related to his interests.

RECOMMENDATIONS

1. All environmental engineers should acquire a basic understanding of biological form and function and the interactions of living systems with emphasis on the quantitative aspects of biology.
2. Academic programs for biologists in environmental biology should include such mathematics, chemistry, and specially designed courses in biology as are needed to acquaint the student with the general nature of that segment of environmental engineering of concern and, in greater detail, the relation of biology to the specific involvement of the engineer with living systems. However, greatest emphasis still should be placed on developing the student's knowledge and skills in the life sciences.
3. Undergraduate students in engineering should be given the opportunity and be encouraged to take fundamental courses in the life sciences. This might be an effective means of attracting more students into the field. Furthermore, by having formal course work in the life sciences at the undergraduate level, the graduate student could either take advanced courses in biology or have more opportunity for engineering courses.

V. SOCIAL SCIENCES IN ENVIRONMENTAL ENGINEERING CURRICULA

INTRODUCTION

In considering the role of social sciences in the education of the environmental engineer it is necessary to evaluate to some degree a number of interrelated questions. What characterizes the world in which the environmental engineer functions? What is the nature of the function he performs? What preparation is needed to enable him to perform these functions, particularly in reference to the social sciences? What specific social sciences does he need? Where should they fit into his educational program?

It is also necessary to consider what limits of definition identify the environmental engineer or describe the *social sciences*. Assuming that in preceding chapters environmental engineering has been sufficiently defined, and leaving to a more appropriate point in the discussion the question of what constitutes social sciences, attention may be directed to the broader background questions cited above.

Objectives and Functions of the Environmental Engineer

The broad objective to which the environmental engineer directs his activities is the control or management of the air, water, and land environments for the benefit of man. Pursuant to this objective he must synthesize strategies from a broad spectrum of specialties to produce the hardware or the systems which represent a unique solution to a specific problem in environmental control. Inasmuch as the objective of this problem solving technique is to make man more comfortably happy, healthy, or satisfied it seems at once self-evident that some knowledge of what man wants, needs, or will accept, as well as of physical laws and systems, should go into the synthesis. For reasons of economics, technology, and human constraints, the environmental engineer is confronted with alternatives at all levels of his activity. Thus he is involved in decision making. In addition, it is a rare situation indeed where altering one aspect of the environment fails to upset a whole spectrum of equilibria in gross or subtle ways. Therefore, consideration of both natural and man-made systems enters into environmental engineering.

To be more specific, it might be said[1] that man seeks to control his environment in three ways: (a) disposing of wastes generated in his life processes or by his exploitation of natural resources, (b) alleviating the effects of incidental contamination generated by human activity, and (c) altering the physical and biological environment to suit his needs.

Much of the attention of environmental engineers has been devoted to the problems created by the direct release into the atmosphere, water, soil, or to underground formations of wastes which we commonly call *pollutants*. There is no doubt that this waste disposal aspect of environmental engineering poses a major problem for a populous and industrialized society. Considerable but less effective attention is directed to incidental or secondary effects of purposeful activities. Such incidental contamination may stem from the fallout of a nuclear explosion; the use of pesticides to destroy unwanted plants, insects, and animals; the application of fertilizers; the addition of preservatives and other chemicals to foods, and the noise that emanates from all kinds of modern instruments, machinery, and groups of people. But by far the broadest array of environmental control activities are those whereby man seeks to alter the world about him and to create and manage systems for his own cultural and social objectives. These include transportation systems, structures of all kinds, alterations in vegetation, the production of domestic animals, and the harvesting of wild game and aquatic life. Each of these calls for a highly organized program of management.

MANAGEMENT OF THE ENVIRONMENT

Regardless of the way in which man seeks to control his environment or the kinds of environment of concern, management programs require three broad classes of information:

1. Physical and biological consequences of alternative courses of action with regard to environmental influence.
2. Value consequences—consequences for human welfare—of alternative courses of action.
3. Estimated responses of people to alternative institutional arrangements (laws, regulations, administrative arrangements, policies) for influencing their behavior with regard to environmental quality.

In other words, those who wish to manage environmental quality intelligently must know first what the physical and biological effects are of disposing of wastes in different ways, of dealing with contaminants by alternative means, and of adopting alternative developmental designs.

It should be possible to define alternatives and the consequences thereof and, if not this, the areas of uncertainty.[2] For example, it might be established that a particular toxic pollutant has temporal and geographical distribution effects. In a simplified sense the alternatives are to live with the disease caused by the pollutant; to try to counteract the pollutant in the environment by treating the disease, the toxicant, or even the environment; or to try to control the pollutant at its source. Selection of alternatives is rarely a simple matter of decision and inevitably becomes more complex when systems rather than specific artifacts are the factors to be managed.

In order to establish a foundation for decision regarding alternatives based on the physical and biological consequences, it is necessary to gain a knowledge of the toxicant cycle (transmission-reservoir), to identify the toxicant source, and to devise a method of breaking the cycle (e.g., environmental management, vector or reservoir removal, or treatment of the recipient or of the source).

Establishing the physical and biological consequences of alternative courses of action is the first step in the analysis. The second step is to make an accounting of these alternatives and their consequences. This accounting needs to include technological and engineering feasibility, economic feasibility, and political and social feasibility. The normal pattern of such analysis is to consider in order the feasibility of going ahead with each of a number of particular courses of action and then comparing these feasibilities. Here three other dimensions are added to the question—the feasibility of alternatives, the penalties and benefits of taking no action at all, and the long-range as well as the short-range consequences of alternatives. The most significant factor in such an analysis, in the context of social science in environmental engineering curricula, is that it requires the use of value judgments and quality determinations as criteria. Values may be reflected in monetary gains or losses, in changes in public health, or in aesthetic satisfactions.

Those who would manage must understand how public policy might be manipulated to achieve different physical, biological, and value consequences. Thus, a knowledge of the structure of institutions and their interrelationships becomes just as important in environmental management as is an understanding of the interrelationships of biota and physical patterns in the aquatic environment. In this context the term *institutions* includes research and development structures, economic institutions, governmental institutions (including legislative, administrative, and legal), and human communities as entities. The analysis is concerned with overlapping or fragmented jurisdiction, with conflicts and cooperation among institutions, and with the degree of employment of analysis of alternatives. Analysis of such qualitative parameters in relation to environmental management is complicated by the fact that jurisdictions are commonly overlapping and fragmented; that conflicts as well as cooperation between institutions are complex in the extreme; and that the degree to which institutional considerations can be intelligently employed in the analysis of alternatives is limited indeed.

Institutions are involved in environmental systems in at least three ways: (a) as strong conditioners of current processes which characterize the existing structure of such systems, (b) as the observable manifestation of patterns of demand, and (c) as vehicles through which various solutions to the systemic problem may be implemented. The first two roles suggest that social institutions can yield empirical information about the supply and demand characteristics of the problem at hand. The third role of institutions suggests they are tools to be purposefully used in executing a desired solution.

Another generic property of environmental systems is the necessity to consider a multiplicity of production processes and, usually, more than one group of beneficiaries as well. This raises the problem of determining an appropriate *objective function* to be used in the analysis of environmental systems. What do these groups want from the resource system in question, and how are these multiple objectives to be weighed in seeking a management solution? This, of course, is a long-standing dilemma within economics which has not yet been resolved in a very satisfactory way on the operational level. The usual discussion takes note of dual, and possibly not fully consistent, objectives—namely, efficiency and equity—suggesting that first and second moments of various economic parameters are appropriate arguments in the objective function.

Finally, communication (message initiation and feedback, cybernetics) is the thread by which natural systems in the environment are held together. Communication (or the lack of it) is the determinant of the final outcome of all attempts at establishing environmental quality. This includes communication between the scientific community and the economic and governmental structures, and between these and individuals who make the final decisions.

Analysis of Environmental Alternatives

In the preceding section attention was called to the fundamental factors identifying the alternatives which must be considered in establishing a program of management of the environment and to the kinds of qualitative inputs which must go into the analysis of alternatives in the decision-making process. The analysis itself involves a spectrum of research and systems analysis procedures and considerations which are relevant to the subject of the world in which the environmental engineer functions and his preparation to perform these functions.

Three fundamental areas of investigation are part of research dealing with environmental management on a broad scale, namely, (a) the identification of the basic problem, (b) the specification of options for purposeful actions relating to it, and (c) the development of an apparatus through which these options are sifted and winnowed in the process of comparative evaluation.[3]

Perhaps the most obvious implication is that environmental management and research must be a team enterprise. The systems which encompass social science problems of environmental management almost always entail more than one physical resource. Technical expertise from a variety of substantive resource areas must be enlisted in the research process. Teamwork also is required on a interdisciplinary basis, as reflected, for example, by the need for close coordination between economics and engineering in river basin analyses.

Over the past decade there has been a change in the character of perceived problems relating to environmental development, management, and use. Problems of current concern are not so much those of supply adequacy but rather those stemming from the impact of technological and social forces on the natural environment. Social institutions require particular attention in the study of resources systems management—as data (reflecting current production, allocation, and consumption processes) and as vehicles for solution implementation. These problems are systemic in nature and require a systems framework for their analysis—often involving several physical resources and calling for a variety of scientific disciplines.

What kinds of criteria can be set up from this systemic approach? Using the *planning-programming-budgeting* technique it might be concluded that every organizational unit concerned with environmental management should be required: (a) to state explicitly its objectives in terms of the services that it expects to provide, (b) to develop the best possible programs for achieving these objectives, and (c) to prepare program budgets showing costs and gains over the life of the program which can be used both in reviewing and approving new programs and in controlling programs after they are authorized.[4,5] Such an approach can be useful for the analysis of environmental problems because in this case, although decision-making emerges from an analytical perspective, the decisions are made in the *public* arena.

The analytical process of systems analysis can also give some perspective, through employment of the following characteristics: (a) the systematic examination and comparison of alternative courses of action which might be taken to achieve specified objectives for some future time period, and the design of additional program alternatives if those examined are found wanting, (b) the assessment of the cost and of the benefits of utility to be gained if the alternative is implemented, (c) a time content of the future, (d) an environment of uncertainty because of the extended time horizons, (e) an analysis which takes place in a broad context with numerous interactions among key environmental variables, (f) heavy reliance on quantitative methods of analysis, but supplemented by qualitative analysis, and (g) a focus on research and development and/or investment types of decision problems.

FUNCTION OF THE ENVIRONMENTAL ENGINEER

From the preceding discussion of the broad area in which the environmental engineer operates it might be stated that his function is to provide the hardware and systems necessary to manage wastes discharged directly into the air, water, or land; to deal with the undesirable secondary effects of activities involving primary good; and to alter natural environments and systems in a manner suited to accomplishing the environmental needs and objectives of man. In the performance of this function he deals with human beings and with their political, economic, social, and cultural institutions, prejudices, and foibles, as well as with physical, biological, and technological systems. Thus both qualitative and quantitative considerations enter into his analysis of a problem: his determination of feasibility; his choice of alternatives; and his final synthesizing of a unique solution to specific problems. Further, he must work with other specialists in related areas of science and have an ability to understand as well as to persuade people. Clearly the environmental engineer should know something of the science that deals with people.

Social Science for Environmental Engineers

In a broad sense the science which deals with people has been termed *social science.* Such a definition, however, embraces such an area of learning that even the *specialist* in social science must limit himself to some specific aspects of the field. Granted the necessity for the environmental engineer to know something of the social sciences in order to perform his function in society, the question immediately arises as to what fraction of the overall field is appropriate. Thereafter, the fraction may be further limited by considerations of the relative importance of specific courses and the percentage of the engineering curriculum which can be allotted to social sciences without an imbalance of emphasis as compared with other educational needs of the student.

In considering the role of social sciences in environmental engineering curricula, the Committee appointed to report on this subject at the Conference first defined what is meant by social sciences. In its written comments to the conferees, on which this report is based, the term was construed to include those aspects or fields of knowledge (other than engineering, the natural and health sciences, humanities, and education) that would be of value to the engineer or applied scientist working with environmental problems.

The Committee considered the social sciences as being of vital importance to the technologist working with environmental problems for the following reasons:

1. The principles, concepts, and established procedures of these disciplines are intimately involved in all environmental problems.
2. Social scientists themselves have now entered the environmental field and are increasingly associated with engineers and scientists in environmental management.
3. Effective communication with social scientists, whether on the basis of team effort or as professionals engaged in environmental management from different points of view, requires that the engineer understand the language, the philosophies, and the approach used by social scientists.

Thus the Committee arrived at the conclusion that social sciences have an important place in environmental engineering curricula.

Specific Social Science Needs of the Engineer

As a prelude to naming specific subject areas in social sciences with which the environmental engineer particularly needs to be familiar, the Committee set forth a list of premises, or ground rules, which might well be applied.

Premise No. 1: Social science courses should have some obvious relevance to the career objectives of the engineer. This was interpreted by the Committee as requiring something more than the traditional English, history, and speech courses which in many institutions fulfill university-wide requirements or option requirements of a particular college.

Premise No. 2: Generally, the social science courses should be developed and taught in the parent disciplines rather than in schools of engineering, or in any event taught by professional social specialists rather than by technologists. The underlying rationale of this premise is that higher quality courses are likely to result and that many engineering problems require an interdisciplinary mix which should find its beginnings in the educational program.

Premise No. 3: Since there is no single engineering program which defines environmental engineering, no single series of social science courses will fulfill the needs of all engineering students. The student should, therefore, be allowed flexibility in selecting the kinds of courses he needs from a block of social science offerings approved for the engineering curriculum.

Premise No. 4: Social science courses should represent a progression of subject matter with some concentrating focus rather than a diverse group of courses at the lower levels of education.

Premise No. 5: Some courses should bring interdisciplinary problems into focus.

Premise No. 6: Social science courses should not be expected to train engineers for *leadership* any more than do engineering courses. They should, however, provide analytical tools which the engineer may use to solve environmental management problems.

Premise No. 7: The social sciences courses should provide the engineer with: (a) a subject matter input that will broaden his perspective on problem solving, (b) an understanding of the strengths and weaknesses of social science analytical tools, and (c) a basis for communicating with specialists in the social sciences.

From the foregoing premises the Committee concluded that courses from the following disciplines and having the following functional objectives are most appropriate:

Economics: The impact of the *market* and of alternative land uses on environmental decisions concerning waste disposal, incidental contamination, and environmental development.

Political Science: The impact of various levels of government on environmental planning and the relation of public and private sectors.

Law: The development of institutions for environmental control and the impact of those controls.

Sociology and Social Psychology: The impact of urbanization, population growth, and increased leisure time on our environment and upon man in that environment.

Business: The impact of business and industry on environmental quality and the development of business structures that will enhance environmental quality.

Communication and Education: The analysis of the nature of decision-making and the impact of public awareness on environmental decision-making.

Planning: The integration of biological and physical criteria with both economic and institutional criteria in stable systems.

Concerning specific subject matter, the Committee recommended that the environmental engineering student should be able to select courses at three levels: (a) basic social science courses, (b) courses in the social sciences that are integrated toward environmental management problems, and (c) courses that integrate social and other sciences. Suggested course context at the various levels was as follows:

First Level Courses
- Economic Theory
- Political Theory
- Communication Theory
- Social Theory
- Psychological Theory
- Social Psychology
- Business and/or Marketing
- Urban and/or Regional Planning

Second Level Courses
- Land Use Planning (Economics)
- Natural Resource Development
- Political and Social Decision-Making
- Legal Structures for Environmental Management
- Industrial Management and Environmental Quality
- Human Population Dynamics and Environmental Quality Control

Third Level Courses (tending toward interdisciplinary; i.e., a mix of social sciences and other sciences)
- Dynamics of Resources in such areas as:
  - Development of Water Resources, Water Resource Planning and Management
  - Regional Air Systems and Climatology
  - Regional Land-Use Planning
- Dynamics of Human Systems Occupation in such realms as:
  - "New City"
  - Recreation
  - Transportation
  - Waste Disposal
  - Environmental Health and Engineering
- Dynamics of Decision-Making in such categories as:
  - Use of Systems Analysis in Arriving at Decisions
  - Institutional Development
  - Technology and Human Values
  - Public Works Administration

The Place of Social Sciences in the Engineering Curriculum

In analyzing the nature of environmental management and the role of the environmental engineer the Committee on Social Sciences found reasons (discussed in previous sections of this report) to suggest that social science should be an important aspect of engineering curricula. Likewise, the nature of subject matter of greatest importance emerged readily from an objective weighing of the evidence. Answers to the question of where social science courses might be added, however, were not so readily apparent. To explore this problem the Committee first sought to determine the present status of social sciences in environmental engineering curricula by a study of the *Register of Graduate Programs in the Field of Sanitary Engineering Education*. This document contains responses from 56 schools listing the formal program courses taught within the department and supporting courses taught by others.

Four institutions reported formal courses in the realm of social sciences. Included was one course in government, one in economics, two in law, two on man and his environment, and six in planning. These data are not particularly revealing, however, because there is no indication that the courses are required of engineering students. Certainly they are available in some department in all institutions; hence, the fact that they are offered in the engineering department reveals little more than that someone in engineering thought them to be of importance. Whether the importance is to the student or to the professor desiring to offer a course is not revealed by the statistic.

Twenty-four (or 43 percent) of the 56 institutions listed supporting courses in their programs that would fall within the social science area. Listings for each of these 24 institutions ranged from one to nine courses and included the following:

Subject	Times Listed
Economics	28
Political Science	8
Planning	7
Geography	6
Sociology	4
Human Relations	1
Law	10
Public Administration	10

How much use is actually made of the social science courses listed is, of course, not known for the aggregate. It is true that social science courses on any campus are available to the graduate student, and an omission in their listing as supporting courses does not mean necessarily that they are not used. It is probably safe to conclude, however, that nonlisting represents nonuse in the majority of the institutions.

Economics is the social science considered most important by the majority of the institutions reporting, with selected courses in law and public administration running poor seconds.

Although there is evidence in the statistics cited of a lack of social science content in environmental engineering curricula, there is no indication whether the omission is due to unconcern for this type of knowledge or an inability to find room for it in the curricula. To each of these points the Committee directed considerable attention.

Concerning the desirability of social sciences in environmental engineering curricula, the Committee concluded on the basis of data contained in the *Register* that environmental and sanitary engineering curricula are generally deficient in the social science area. Further, that if the engineer and applied scientist are to continue to discharge their professional responsibilities and be able to work with others in a team effort in attacking environmental problems, it will be necessary to improve their education in the social sciences. Two possibilities for how this might be achieved were presented:

1. Development of special formal courses in social sciences by parent disciplines. This, it was postulated, would make the best use of student time. However, to assemble enough students to justify special courses in other departments the Committee suggested that other academic departments interested in such courses might be enlisted to support the courses. A minimum of two courses was suggested: (a) natural resource economics, and (b) planning, within institutional and legal constraints.
2. Purposeful and continued effort of professors in the major department to relate their instruction to the overall system involved and how it relates to man and his well-being.

From the point of view of desirability of social sciences in environmental engineering curricula, without specific resolution of the problem of how a curriculum can accommodate the necessary courses, the Committee made three recommendations:

1. All M.S. programs should contain at least one, and preferably two, well-integrated social science courses taught by social scientists; and the doctoral programs should contain at least three of these courses as a minor for those planning to enter professional practice. Recognizing that some master's programs may choose to place heavy emphasis on the technological aspects of one environmental specialty (e.g., water quality), it is believed that a carefully designed seminar program could serve to add the elements of breadth of purpose and real-world flavor to such a program.
2. Program administrators should review course offerings with their faculty to determine where and how the faculty can better relate their courses to the overall system and the needs of man. Some faculties now do this quite adequately, others do not have the background, and others are not interested. There is probably little that can be done with those not interested. For others, it may be of value to conduct summer workshops similar to those now conducted by AAPSE in technological subjects.
3. A faculty should offer the maximum opportunity for its students to participate in class discussions where an awareness of the social sciences and man and his environment can be developed.

With specific reference to the problem of incorporating social sciences in environmental engineering curricula, in line with its own recommendation, the Committee presented a number of suggestions. These, and the concensus of the conferees, are interpreted in this report in relation to the nature of environmental engineering and degree programs.

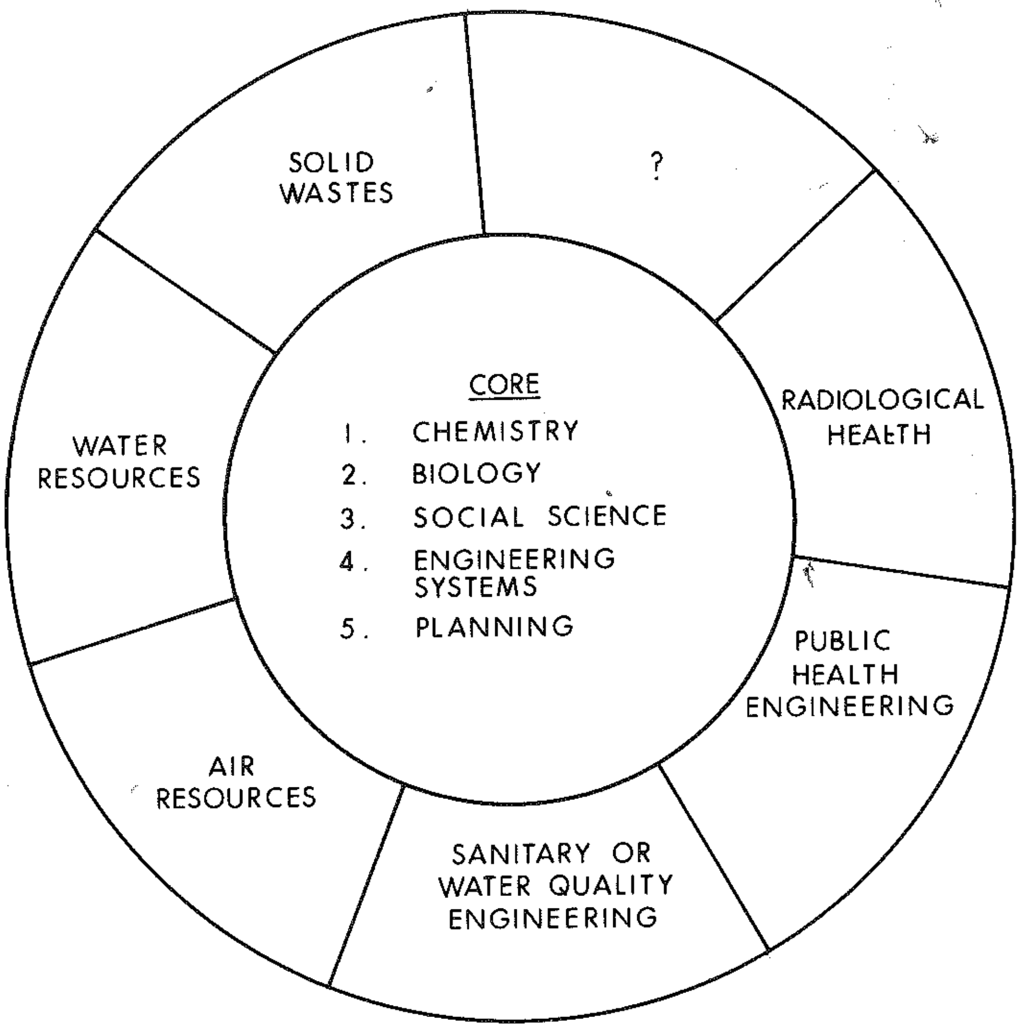
A CONCEPTUAL APPROACH TO ENVIRONMENTAL ENGINEERING CURRICULA

Adoption of the term environmental engineering, whether opportunistic or in response to a need to open up traditional curricula in sanitary and public health engineering, led to considerable pressure for specialty areas to be set up at the master's level. Over a period of years the list of these included radiological health, air resources, water resources, solid wastes, and municipal engineering, to name the most common. At the same time there was no change in the need for environmental engineering to include in the solid core of its curricula courses in chemistry and biology and some introduction to systems engineering.

To overcome the dilemma posed by the foregoing developments, the Committee suggested that environmental engineering should be the *umbrella* designation for a spectrum of curricula built around a common core, each adding its own specialty subject material. The concept, called *keyhole* by the Committee, is illustrated in the following figure in which a number of possible specialty areas are shown without reference to the particular courses which constitute the specialty.

This concept, considered novel by the conferees, was not adopted for several major reasons:

1. At the master's level the core itself becomes overwhelming unless a two-year requirement for the degree is adopted. While this might be feasible eventually, there is no agreement that it should be imposed at this time.
2. At best, the social science content of the core cannot include more than two courses if the demands for chemistry and biology are to be met. No one is particularly inclined to reduce these basic needs in favor of more social science. Therefore, courses would have to be either (a) survey courses, which are not likely to emerge from social science departments or be of great value; or (b) selected courses, which are already available and can be worked into existing curricula outside the core, in resource economics, planning, institutions, and law.



3. Many major schools of sanitary engineering are built around a hard core of water quality engineering, plus chemistry and biology, and see no urgent need to change in the face of other limitations in the prospect for social science additions to the curriculum.
4. Several of the proposed specialty areas do not in fact justify treatment as separate curricula because of the limited content of subject matter involved.

Degree Programs

A location for social science courses in the curriculum other than at the master's level was explored. Realistically, it must be admitted that environmental engineering exists only at the graduate level, because undergraduate curricula were largely stripped of engineering content to make room for humanities, which include some social sciences. It is therefore evident that if social science deficiencies in the engineering curriculum exist, they can now be corrected only at the graduate level. It is equally evident that the master's degree program is now a technological specialty, whereas the Ph.D. or Eng.D. programs again offer room for broader general education. In this situation it is unrealistic to ask that the master's curriculum become another broad educational experience.

The conclusion is inescapable that the alternatives are:

1. Add more courses the engineer *ought to take*, without concern for how he ever becomes an engineer.
2. Extend the period of education required for the master's degree under some sort of guarantee that the time added will be utilized in social science rather than consumed by additional basic science courses and a proliferation of engineering courses.
3. Generate an entirely new concept of environ-

mental engineering, possibly with a two-year educational period for some students without sacrificing the one-year master's program of others.

4. Continue as at present, with breadth of education at the bachelor's and doctoral levels and specialty education at the master's level, albeit with all possible latitude for individual schools to meet the needs of individual students.

The consensus of the conferees generally favored the last of these alternatives, not because of any lack of feeling for the deficiency of environmental engineers in the social sciences, but because other alternatives are less acceptable at this time.

Both the Committee and individual conferees explored the question of what effect the environmental engineer has had on public attitudes toward pollution, in contrast with the effect the citizens' alarm about the state of the environment has had on engineering activities. There was a considerable feeling that the engineer is *not* today insensitive to public affairs and that any lack of effectiveness in the political arena is not closely linked with the presence or absence of formal courses in the social sciences.

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Note: The authors of this chapter have drawn freely upon the ideas of others and in particular the following:

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VI. PLANNING OF ENVIRONMENTAL SYSTEMS

The Committee on Planning of Environmental Systems was charged with the responsibility of examining the educational requirements for engineers concerned with the planning of environmental systems with emphasis on computer applications and the mathematical theory of decision and control. It is the Committee's judgment that the subject has broader implications for the improved graduate education of environmental engineers than connoted by the concept of planning in the ordinary meaning of the term. Rather than viewing this topic as a new specialty to be added to the expanding list of useful areas of study, environmental systems analysis should be regarded as reinforcing older topics and infusing them with new perspectives and offering attractive possibilities for more effective teaching and more efficient learning. A breakthrough in applied mathematics has taken place in the last 20 years, and this breakthrough, coupled with the development of interactive computer processing, is causing profound and irreversible changes in all fields of engineering.

Taking a long view of engineering education in the twentieth century, two important but conflicting trends are prominent. In the first place numerous reports of the ASEE, the NRC, and the President's Science Advisory Committee have consistently stressed the need for unity of goals in the education of engineers and a homogeneity of standards in the various branches. At the undergraduate level this has been manifested to a large degree by emphasis on the sciences, the engineering sciences, the fundamentals of technology, with the purpose of offering a high-level specialized technical education while enabling the graduate to practice in a variety of fields. Concomitantly, there has been a second trend reflecting the pressure for even greater diversity in the engineering curriculum. The result has been a broadening of the content of curricula to include social and humanistic studies. Other types of courses, e.g., statistics, have been added to the core requirements for all engineers. These trends, which are part of the complex evolutionary process of industrialization, have resulted in longer periods of education. The vertical and horizontal expansion of education has given rise to conflicting opinions as to what subset of the whole should constitute the minimum requirement for the professional degree.

In resolving this important issue and in forming judgments on the question of accreditation, consideration must be given to the impact of the breakthrough in applied mathematics and of the development of interactive computer processing on the graduate education of environmental engineers. The computer revolution has made possible an integrated and consolidated approach to broad problems in the physical, social, and life sciences that heretofore were resolved by separate specialists with fragmented points of view.

The innovations in applied mathematics since World War II of Von Newmann, Dantzig, Kuhn, Wolfe, Charnes, Bellman, and others have greatly extended the range of problems amenable to mathematical treatment in the biological, physical, and social sciences that underlie engineering application. The extension is due to several factors, including: (a) the use of an increasing variety of branches of pure mathematics with the development of new techniques for handling classes of problems that previously were intractable; (b) the increased capacity for information processing with the advance of computer science; and (c) the growing recognition of the power of mathematical analysis in traditionally non-mathematical social sciences, such as economics, sociology, and psychology. In the natural sciences the advance of applied mathematics has blurred the boundaries between physics, chemistry, and biology; and the transfer of techniques and concepts of the more basic sciences into the applied areas is occurring at a rate so rapid that some older categories of knowledge have become completely reoriented.

With the development of interactive computer processing, including two-way graphical communication between man and machine, we are entering an era in which man's intuitive and evaluative ability will be melded with electronic information centers by the manipulative power of the computer. The potentialities of man/machine dialogue for technical design and planning are great, and nowhere in the near future are they more impressive than in the graduate education of environmental engineers. The powerful reaction produced by mixing graduate students and fireside consoles is difficult to describe and probably must be seen to be believed. Professors who have seen the process believe that in some institutions and educational situations the conventional calendar system of classes and grades must be replaced by the *tracking* of individual students, each proceeding at his own best pace. The development of interactive processing has profound significance for professional education and accreditation.

The implications of the change are important to all engineers and especially to environmental engineers. Failure to put the new mathematics and the computer utility in a central position in the educational process will mean a failure in full realization of technology for social and economic improvement. Brooks[1] has commented on this point as follows:

> "To an increasing degree, engineers are failing to realize the benefit of technology because of a failure to view technology in the context of an entire system, a system that in-

cludes the social and economic context in which technology operates, as well as its interaction with the total physical environment. Only in the fields of electronic communications and in the generation and transmission of power has it been possible to realize the benefits of a truly integrated technological approach to meeting a defined social need. By contrast, the field of transportation and the field of environmental control have suffered from excessive fragmentation, fragmentation of industry in terms of special vehicles techniques, or products, and fragmentation of government in terms of specialized goals or limited constituency. To an increasing degree, it is being realized that the world is interdisciplinary. To ignore this is perilous.

"This is the fundamental problem with which engineering education is now struggling, and in no discipline is it of greater concern than in civil engineering. The answer cannot be merely in interdisciplinary type education because one individual cannot know everything; yet the engineer, particularly the civil engineer, must learn to communicate with all the scientific specialties that may affect him, and must learn how to extract significant and relevant facts from new sciences as soon as they develop."

Experience in the past five years with the systems approach in a few universities and government agencies has demonstrated its effectiveness as a medium of communication among groups concerned with resource development and conservation. In teaching and interdisciplinary investigation the expectations of early proponents of environmental systems analysis are being realized. Gotaas and Logan,[2] writing in 1959, discussed conventional planning and delineated a new type of graduate program in civil engineering:

"While planning has tended to become an art, rather than a science, now thanks to progress made in the field of operations research and systems engineering, planning need no longer be a vague, idealized concept. The application of quantitative analytical methods involving numerical analysis (for which the engineer is uniquely trained) makes it possible to think of physical planning and the related areas of engineering decision-making in measurable and, therefore, comparative terms. Because of the great significance of planning in the work of the civil engineer, it is suggested that fundamental analytical work in planning should be a core subject of civil engineering education beyond the basic fundamental science and social science preparation. Planning could become the framework into which the specialized disciplines of civil engineering such as structures, hydraulic engineering, sanitary engineering, water resources, highways and transportation engineering could be more logically established. An understanding of planning could provide engineers with a better appreciation of design criteria, and would help in developing rational approaches to the prediction of future technological needs. By using techniques similar to those developed by operations research and systems analysis organizations during the past few years, it should be possible to make rational predictions of the types of developments in physical facilities, areas, factories, schools, and other aspects of the environment which might best meet the needs of the country in the future."

At Cornell, Harvard, Northwestern, Stanford, and other universities that have pioneered in introducing the systems approach to resource management, recent experience has demonstrated that environmental systems analysis provides a versatile superstructure for integrating the contributions from different disciplines and for incorporating data and interrelating research from many fields. In the process of constructing a large model of an environmental system, the computer program provides a helpful bridge of communication between different groups of specialists. Moreover, the model provides valuable guidance for research efforts and permits the engineer, the chemist, the biologist, the economist and the political scientist to see how small but vitally important pieces of information and theory can be fitted together and to see where there are critical gaps in existing knowledge.

The benefits of the systems approach as a central part of the graduate education of environmental engineers more than compensate for the cost of the additional investment in applied mathematics. For the student, perhaps the most significant part of the profit is his enhanced learning efficiency in the related sciences. First-rate textbooks, such as *Linear Programming and Economic Analysis* by Dorfman, Samuelson, and Solow and James Coleman's *Introduction to Mathematical Sociology*, provide effective highways to the heartland of the social sciences. The mathematical techniques used in these texts are the same as those needed in the analysis of systems for disposal of solid wastes or in the selection and balancing of the unit processes of a waste treatment plant for a paper mill. And the computer algorithms for solution of waste transport problems in tidal estuaries are similar to those in use at the frontiers of research in some areas of physical chemistry. In its report on basic research in U. S. chemistry, [3] the NAS-NRC Committee for the Survey of Chemistry states:

"A clarification of basic kinetic theory and of the macroscopically irreversible approach to thermodynamic equilibrium has been contributed in the last few years by a method, making use of diagram techniques, due to I.

> Prigogine (Belgium) and collaborators. This has provided a unified practical approach to computation of transport phenomena in systems as diverse as dilute gases, plasma, and electrolyte solutions."

TERMS AND CONCEPTS

Before moving to questions relating to courses and curricula, it may be helpful to discuss certain terms and concepts related to environmental systems analysis. In order to minimize confusion the Committee deems it desirable to comment briefly on two terms commonly used in environmental planning, viz., *operations research* and *systems analysis*. Some individuals have found it useful to distinguish between the activities carried on under each of these labels. The Committee believes, however, that in the present context no useful purpose is served by making such distinctions. It has agreed that the term systems analysis is more appropriate in the environmental engineering setting and thus will restrict itself to this term exclusively when referring to these analytical and computational approaches.

It should be clear that there is a hierarchy of goals associated with these approaches. This is relevant, since the question is sometimes raised as to whether mathematics and the computer are means or ends. The primary goal for any systems analysis is to provide information and to examine the consequences of alternative courses of action with respect to the real-world situation under study. In this context it is clearly a means to the end of improving engineering decisions. However, it is also frequently necessary to become involved in studies of means (i.e., the analytical techniques) in order to reach the primary goal. The problem settings and pertinent phenomenology in environmental engineering are much too complex and the analytical methods too little developed to take a position that concern should be restricted exclusively to ends rather than means. Environmental research must be concerned with both, as the primary goal of engineering is to solve problems of the real world, and to achieve this goal, it is necessary to understand these problems in light of modern science and technology and to possess analytical skills that effectively deal with the manifold interactive elements.

In making judgments pertaining to requirements for systems analysis in graduate curricula, it is necessary to recognize the wide diversity of activities that are being labeled environmental engineering. This term describes work ranging from research employing the most sophisticated analytical and experimental methods to fairly routine application of stable and reliable technology. In general, the two familiar categories, *engineering practice* and *engineering science*, will serve the purposes of this discussion of courses relevant to systems analysis; but, since systems engineering is a new discipline, a few comments may lessen the hazard of a semantic haze.

Systems analysis often is an essential aspect of practice. But if this entails only the routine use of well-understood techniques of operations research, such activity does not fall within the scope of engineering research as commonly defined. However, studies by engineering students of the planning of environmental systems may introduce new mathematical techniques and may even advance the frontiers of knowledge in some parts of social science (e.g., human behavior in systems with hydrometeorological uncertainty). There are opportunities for research at the interface of engineering and management science. A creative investigation of this type merits a status as engineering science on a par with, say, a creative investigation in santiary chemistry using the newest techniques of nuclear-magnetic-resonance spectrometry.

In view of possible semantic difficulties that may accrue to older connotations of the terms *practice* and *science* in areas of engineering planning in which physical science and social science are on an equal footing, our Committee would direct attention to a categorization of these terms by Willenbrock, Brooks, and Abernathy.[4]

> "*Engineering practice* refers to the creative application of existing knowledge to the solution of specific engineering problems. It is not concerned primarily with the development of new knowledge or of generic solutions extending beyond the particular problem attacked.
>
> "Instruction for engineering practice was the primary aim of the four-year undergraduate programs in colleges and universities before World War II. The increasing complexity of engineering practice of today has put these programs under considerable strain. There are increasing demands for men with (1) more generalizable scientific and mathematical skill, (2) more managerial and administrative ability, and (3) more concern about social, political, and economic aspects of engineering. Such demands can be and are being met in a variety of ways.
>
> "Some of the characteristics of engineering practitioners are:
>
> 1) an ability to handle mathematics and science related to a general area and to handle problems not in handbooks,
> 2) a greater concern with finding a needed solution to a specified problem than with an understanding of all aspects of the science or mathematics involved,
> 3) an ability to synthesize practical designs

which satisfy a number of requirements, several of which may be in conflict,

4) a sensitivity to economic factors and an ability to effect trade-offs between partially conflicting objectives,
5) an ability to utilize formal technical background and practical experience to solve problems which are new in detail, but not new in concept,
6) an ability to direct large-scale technical operations by coordinating and supervising the efforts of appropriate specialists.

"There are several possible educational patterns for engineering practitioners. In fields where practical experience is of greater value than academic work, a four-year academic program plus a planned program of practical experience might be the most satisfactory. In fields where a higher degree of mathematical and scientific background is needed, a five- or six-year program leading to a Master's degree plus industrial experience could be the best preparation. In fields characterized by highly intricate economic and political considerations, a four-year engineering program which is then coupled with graduate work in law or in public or business administration could be most desirable.

"An important consideration in training for modern practice is that the science and mathematics taught should not be confined to what is thought immediately relevant to current technology. Rather, it should provide a basis for future learning, and hence aim at comprehensive understanding rather than the mere acquisition of useful techniques.

"By *engineering science* is meant those fields of science which are of interest primarily from the standpoint of applications. The aim of engineering science includes comprehensive understanding and explanation of phenomena as a basis for the analysis and prediction of the engineering performance of systems. It also includes the sciences which deal primarily with the performance of man-made systems as contrasted with natural phenomena. Examples in the first category include fluid and solid mechanics, thermodynamics, and solid state device physics. Examples in the second category include communications theory, control theory, and the computer sciences. The engineering scientist is interested in developing generic solutions to whole classes of engineering problems and in laying the foundations of design theory and engineering analysis. He is not primarily interested in finding particular solutions in specified time-limited engineering situations.

"Since World War II, it has been evident that there is a need for men who have an educational background essentially similar in content to that of a scientist interested in basic research, but who have in addition a strong interest in the utilization of scientific understanding and mathematical techniques for the solution of problems which are important from an applications standpoint.

"Engineering scientists are usually educated through to the Ph.D. and frequently have undergone additional post-doctoral education. They are rarely involved in design, except as an incident to the development of experimental equipment, and they seldom work under tight economic constraints or to rigid time schedules. In most cases, they are highly skilled in mathematics or one of the physical or life sciences.

"Engineering scientists will usually be located in academic institutions, in industrial corporate laboratories, or in government or national laboratories which cover a very broad spectrum of technology. They will often be found serving as consultants or engineering specialists in development projects, but not as members of design or production teams."

CURRICULUM REQUIREMENTS

Topics from a broad spectrum of applied mathematics are useful in environmental systems analysis and engineering planning. It is important to state, however, that there is no clearly defined threshold of mathematical expertise that must be passed for entry to the field. Environmental engineers and scientists with widely differing personal investments in mathematics have made useful contributions. In mastering the first and most basic techniques of computer mathematics, the student markedly strengthens his grasp of classical engineering mathematics, much of which is useful in systems engineering.

However, this committee is in agreement with the ASEE Committee on Goals of Engineering Education in advocating the systems approach throughout the entire mathematical training of engineers.[5]

> "Throughout the curriculum the student should have experiences with synthesis and analysis in research and design. In the last year of his basic engineering program a fairly sophisticated engineering system design project might be undertaken which would then constitute the capstone of the program. The aim is to encourage creativity. This pedagogical capstone should integrate the learning experience of the entire curriculum and bring to bear the knowledge and tools the student has acquired. Judgment and innovation should be encouraged. In the design project the student should gain experience in the use of optimization techniques and decision theory which require consideration of performance, scheduling and cost."

The desiderata pertaining to undergraduate mathematics summarized in this paragraph are already being realized in large part at some engineering schools such as those at Dartmouth College and Carnegie Institute of Technology. Other schools are also making rapid progress at the undergraduate level in programs emphasizing the systems approach in functional and detailed design of complex engineering works in which socio-economic problems are examined in their entirety. However, it is expected that overall, nationwide progress in this direction will be uneven and probably disorderly. Time-sharing systems are costly and engineering schools need funds to make these complex devices available to students. However, the prognosis for progress at the graduate level is favorable. Therefore, in the following discussion of instruction in environmental systems analysis at the graduate level, our committee has assumed that facilities and funds for computation will not be in short supply.

In order to simplify the presentation of subject matter, the formal course needs for Ph.D. and Eng. D. students majoring in *environmental systems analysis* are discussed first. Attention next is given to Ph.D. students taking a minor in this subject; and finally the requirements at the M.S. level are discussed. It should be understood that the basic core courses listed, like all mathematics courses, can be taught at different levels of rigor and generality appropriate to the goals of different schools.

Ph.D. or Eng. D: Major Field in Environmental Systems Analysis

In setting forth a doctoral program in environmental systems analysis it is presumed that the student has previously received sufficient academic preparation in one of the fields of environmental engineering (e.g., sanitary engineering or air resources engineering) such that he is capable of identifying meaningful problems and dealing with their physical, chemical, or biological constraints. Normally this would be best attained through a master's curriculum having a professional orientation in one of the environmental engineering specialty areas. The following list of courses and topics is useful in development of the core of knowledge common to the mathematical formulation and analysis of the decision problems encountered with environmental systems:

Theory of Probability—Axioms of probability, combinatorial analysis, random variables, univariate and multivariate distribution theory, expectation, generating functions, sequence of random variables, central limit theorem, laws of large numbers. (Prerequisite: advanced calculus, engineering statistics.)

Optimization of Deterministic Systems—Formulation of mathematical programming problems; duality theory of linear programming; computational methods for linear programming; assignment, sequencing, and combinatorial problems, integer programming; decomposition principle; nonlinear programming: Lagrangians, Kuhn-Tucker theorem, gradient techniques, search methods. (Prerequisite: advanced calculus and linear algebra.)

Numerical Analysis—The approximation of functions and the solution of equations. Topics include polynomial interpolation, numerical quadrature, and iterative procedures for algebraic, transcendental integral and ordinary differential equations. Laboratory exercise to consider the organization of mathematical problems for solution of digital computers. (Prerequisite: advanced calculus and linear algebra.)

Stochastic Processes—An introduction to stochastic processes with emphasis on discrete models such as random walks, recurrent events, Markov chains and branching processes; processes connected with the Poisson process, e.g., birth-death processes and applications to queuing systems; continuous-time Markov processes and Gaussian processes. (Prerequisite: theory of probability.)

Decision Theory—Foundations for decisions under uncertainty; Bayesian inference (prior to posterior analysis); sufficient statistics; applications to Bernoulli, Poisson, and normal models; expected value of perfect and sample information, optimal sampling schemes; regression and correlation; sequential sampling. (Prerequisite: theory of probability.)

Dynamic of Systems—Review of dynamic systems under deterministic and random inputs. Calculus of variations and dynamic programming approach to the optimization of dynamic systems. Controllability and observability. Optimal estimation of the state of dynamic systems. Numerical methods for the solution of optimal control problems. Differential games, stochastic optimal control. (Prerequisite: Optimization of deterministic systems, theory of probability.)

In addition to courses listed above, which will require about one academic year, the student should participate in a research seminar involving one or more applications of environmental systems analysis to specific problems or regions. Moreover, it is desirable to take a *work shop* course in the uses of the computer to solve problems extracted from the material in the six basic courses. In some cases it may be appropriate to substitute one (or two) courses in mathematical statistics or mathematical economics in place of one (or two) of the basic courses in systems analysis. One or two courses or even full minors in welfare economics and public investment theory are highly desirable.

Ph.D. or Eng. D: Major in Specialty Area of Environmental Engineering

Students majoring in sanitary or air resources engineering who desire a minor in systems analysis should complete at least three of the basic courses listed under this major. They might also take a graduate course in their specialty in which functional and detailed design are approached from the systems viewpoint. A course in mathematical statistics covering the design of experiments (regression and analysis of variance) might be substituted for one of the three basic courses. Computer experience is essential and participation in a research seminar in environmental systems analysis is desirable.

Master's Degree in Environmental Engineering

In most cases there will probably not be room in the curriculum for even one basic course in systems analysis. (If there is, it should be the *optimization of deterministic systems*.) However, engineering students are increasingly covering some of the basic material (particularly matrix algebra, linear programming, and introduction to numerical techniques and computer programming) at the undergraduate level. With these students and with professors of engineering who have competency in systems analysis, a great deal can be done in a one-year program of graduate study to introduce the leading ideas of systems methodology in engineering courses in water supply, water quality management, unit processes of treatment, air pollution control, and solid waste disposal. Reinforcement of the effort is possible in certain phases of the related sciences—for example, in the ecology of lakes and streams and in the theory of rate processes and chemical equilibria of sanitary chemistry. In schools in which several faculty members have competency in systems analysis, the methods can be employed in several of the courses. In other cases it may be more efficient to present the techniques at an elementary level in a one-semester course with applications in the different segments of environmental engineering.

Master of Engineering Degree in Environmental Systems Analysis

The student in a two-year master's degree program in a specialty area of environmental engineering wishing to develop competence in systems analysis would take courses similar to those suggested in the minor in systems analysis. In most instances, however, a graduate course in mathematical statistics should be included.

PROGRAMS AT CORNELL AND HARVARD UNIVERSITIES

The method of education in systems analysis that has been used at Cornell University for the past five years has been to provide all sanitary engineering students in the doctoral program with a one-semester course which introduces the following topics:

1. Systems approaches to complex problem solving
2. Matrix algebra
3. Selected topics in calculus
4. Mathematical programming
5. Theory of games
6. Stochastic processes and simulation
7. Applied welfare economics

The course makes extensive use of examples in the areas of water resources and sanitary engineering. Obviously the range of topics cannot be covered in great depth, although considerable effort is given to providing the theoretical basis for the methods discussed. Those doctoral students who are interested in doing research in which these approaches are useful are encouraged to minor in industrial engineering (operations research) and economics (welfare economics). After increasing their competence in these areas they are brought into seminars (led by faculty from environmental engineering) to again focus their attention upon real-world problems.

At Harvard about half the students in environmental engineering specialize in systems analysis, and most of the others take at least one course in which it is emphasized. The principal introductory course is titled *Public Investment: Techniques for Relating Economic Objectives, Engineering Analysis, and Government Planning* and is taught by members of the faculties of government, economics, and engineering. The course is presented in three coordinated sections: (a) objectives of public investment (multiple objectives in public investment programs; weighting of objectives in the political process); (b) formulating public investment criteria (national income and its distribution; accounting prices; interest rates; uncertainty); and (c) applying criteria to project design (the design process; methods of analysis; problems of measurement; deterministic and stochastic models; simulation). In addition to this introductory course (and in addition to mathematics courses in the theory of decision and control), several advanced engineering courses are offered in the design of water resource systems and operations research in environmental engineering. In an advanced topics course taken by Ph.D. candidates in environmental systems engineering, the subject material includes simulation techniques for multistructure systems and methods of multivariate analysis, including spectral analysis of hydrometeorological time-series.

DISCUSSION

The Committee believes that it is desirable to put systems analysis in a central position in the graduate education of all environmental engineers and some environmental scientists. It may be necessary to do this in order to attract and motivate first rate students who have had excellent training in applied mathematics at the undergraduate level. The benefits of systems analysis for the future of environmental engineering may be summarized as follows:

1. Improved methods of engineering planning will result and will make possible the incorporation of quantitative techniques of economic and social analysis into engineering plans.
2. More efficient systems for the collection and collation of data relating to the environment will evolve.
3. Extensive automation and codification of design and operating procedures for important engineering subsystems will become attainable.
4. The revision of many classical design methods by the incorporation of more realistic assumptions and approximations will be brought about. Such incorporation is now possible with the advance of applied mathematics and computer capability.

It is pertinent to emphasize that in a strict sense the analysis of systems has always been a prominent part of engineering. Sanitary engineers will recall that since the days of Chadwick, the supply of water and disposal of sewage have been managed systematically. Considerations relating to partially conflicting objectives, inadequate data, uncertainties in benefits, and the effects of inaccurate projections of demand growth were all weighed by early engineers in a rough balance by a process that undoubtedly put a heavy premium on *engineering judgment*. Although this was a kind of systems analysis, it is probably true that much design methodology and many quality standards were developed over the years in the context of loosely defined economic and social objectives. Today, with the development of the logic of planning and the advance of applied mathematics, a new generation of engineers aspires to create and to apply methods of systems analysis of ever increasing power for the benefit of man. In educating these men, we believe that evolutionary changes are needed in the presentation of the technology of environmental management and that these changes should be in the direction of emphasizing environmental systems analysis in the curriculum. Programs will be strengthened and teaching made more effective when new concepts, such as the Kuhn-Tucker theorem, the decomposition principle of mathematical programming, and the social rate of discount, receive equal billing with important, traditional concepts, such as the law of mass action, Bernoulli's energy theorem, and the momentum principle.

The needed changes should be evolutionary rather than revolutionary and there are many opportunities in the field of environmental management for the application of systems analysis and modern applied mathematics. These range from small systems to large ones, and it is convenient to identify five levels of size: (a) *microsystems of environmental science* (laboratory studies of fundamental phenomena); (b) *engineering devices* (pilot plant studies of a unit-process or a control unit); (c) *engineering works* (an entire treatment plant, dam, or aqueduct); (d) *project-size systems* (a set of coordinated works, usually multipurpose in scope, such as those used in the development of water resources of a river basin or in the control of pollution in a sanitary district); and (e) *multi-project systems* administered or coordinated at the state or federal level of government. As examples of systems at these five levels of size the following are illustrative? (a) *microsystem*, an investigation of the mechanism of disinfection by chlorine of coliform bacteria; (b) *engineering device*, the design of a set of fiber-filters for simulating the respiratory deposition of radioactive airborne materials;[6] (c) *engineering works*, the design of a treatment and disposal system for a kraft paper mill;[7,8] (d) *project-sized system*, the design of a transport network for refuse collection and disposal;[9] and (e) *multi-project system*, a plan for land and water development of West Pakistan.[10] Harrington[11] has made a survey of a wide variety of applications of systems methods in environmental control and has classified these as to mathematical technique and as to fields of application.

In conclusion, the following list of topical problem areas is presented to indicate possible applications of the techniques of systems analysis. It is intended to be representative rather than exhaustive. The techniques are especially useful in elucidation of relationships between interacting elements of the system. Although in many of the problem areas a start has already been made in formulation, in most cases, however, this has been done by classical methods of applied mathematics rather than by techniques of systems analysis. Usually, therefore, the models apply to steady state conditions with deterministic inputs. Dynamic or nonstationary cases generally have not been examined in detail, and not much work has been done on realistic stochastic models. As a result, more analytical investigation is needed to determine optimal operating conditions and efficient designs. We believe these topical problem areas provide opportunity for deployment of a dynamic programming and response surface analysis. The systematic use of these methods leads invariably to improved insight into the nature of particular phenomena and the effects of various types of controls:

1. Optimization of treatment-unit designs using accepted design criteria as constraints.
2. Dynamic modeling and simulation of raw waste loads through the treatment plants with generation of time-variable effluent.
3. On models of plant units, evaluation of effectiveness of individual waste control schemes, including, for example, different rates of sludge return and also the by-passing of particular units. This would be essentially a computer-operated *pilot plant* model to test different operational control procedures.
4. In anaerobic digestion, the evaluation of different stages of processes using mathematical simulation and including the examination of any *feedback* bacterial processes and the dynamics of the liquefaction and gasification stages.
5. Mathematical modeling of the dynamics of solution chemistry in natural waters.
6. Simulation and quantitative analysis of the more important features of the nitrogen cycle in lakes or stabilization ponds, including feedback loops to determine optimum conditions for a balanced system.
7. Input-output analysis of effects of nutrients on algae growth, including the examination and synthesis of response times in various systems.
8. Simulation of bacteria-protozoa dynamics in streams and treatment plants under different environmental conditions.
9. Simulation and modeling of the major features of bacteria-algae symbiosis.
10. Modeling of column-flow phenomena in ion exchange and absorption, with hydraulic parameters varying over time.
11. Computer simulation of meteorological phenomena (winds and air density patterns) in a metropolitan area with several sources of air pollution to determine the spatial-temporal frequency distributions of pollutants at various control points and to ascertain effects on these of various schemes of pollution abatement at the sources.

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VII. NON-ENGINEERING STUDENTS IN ENVIRONMENTAL ENGINEERING PROGRAMS

Concern for realistic solutions to environmental problems is presently being expressed by leaders from all sectors of our society who view with alarm the rapidly growing maze of interactions in today's socio-technological world. The sanitary engineer, who has in the past filled the role of generalist as well as expert in the field, cannot continue to stand alone as a buffer between society and its environmental problems, even those of the air-water environment where his concern and competence have been greatest. An improvement in the situation could be brought about through the use of teams of specialists, each member of which should have an awareness of the total problem while also lending his particular expertise to the total solution. There can be no question of the desirability of generating such a team approach. Its success, however, depends upon a community enthusiasm for the broad type of problem, a willingness of the scientist to lend his expert advice to the team effort, and, most of all, the devotion of sufficient time by the scientist to learning and appreciating the intricacies and limitations of applying pure science to solutions of problems in the real world. Each of these three elements is an essential ingredient in the success of the team approach. But perhaps the most important aspect of the problem lies in the actual recruitment of adequate numbers of competent scientists to permit general utilization of the team approach.

There are at least three possible avenues for educating non-engineering personnel for roles in environmental engineering and science:

1. Recruit graduates of baccalaureate and master's programs in the physical and biological sciences to enter programs of sanitary or environmental engineering to pursue advanced engineering degrees.
2. Recruit science graduates to enter engineering departments for graduate education with the objective of obtaining advanced non-engineering degrees.
3. Recruit science graduates to pursue advanced degree programs in their own academic departments, with these programs emphasizing environmental problems and providing the opportunity for contact with the engineering sphere through engineering minors and dissertations jointly supervised by science and engineering faculty.

In addition to encouraging non-engineers to enter the environmental field, there remains, of course, the present trend of including strong science minors in the doctoral programs of engineering students, thus providing equivalent inputs of engineering and science to the resolution of environmental problems. From the point of view of the total manpower problem, bringing science graduates into the field would be most desirable. Moreover, by providing engineers with stronger backgrounds in science, but not expecting them to function as scientists *per se,* the efficiency of the engineer-scientist team should certainly be enhanced.

The Committee agreed that the maintenance of the non-engineer professor at the peak of his abilities in his specialty requires that he work with other scientists of his own kind and function optimally within the spheres of both science and engineering. Where the academic atmosphere is suitable for this type of development it should be encouraged. The hazard lies in the lack of sufficient orientation to real problems and the proper development of the enthusiasm for the types of environmental problems which are in need of solutions. While the consideration of environmentally oriented programs in science departments is probably desirable, this was not the charge of the Committee. So, beyond recognition of this possible answer to meeting the need for scientists, the Committee wishes to direct its principal attention to the bringing of non-engineering students into contact with the engineering environment.

There are two logical alternatives available to non-engineering students wishing to enter engineering departments at the graduate level.

1. The non-engineer may enroll in an environmental engineering curriculum and be expected to make up certain prescribed undergraduate engineering courses. He would receive an engineering degree on completion of the program.
2. The non-engineer may seek an applied science degree, administered by the engineering college or department thereof. Here the engineering matriculation requirements would be minimum or nonexistent.

The majority of the Committee believed that to insist that the non-engineer seek an engineering degree (i.e., the first alternative) is to ask him to leave his specialty and, at the same time, perhaps to develop from this non-engineering applicant a rather undistinguished type of engineer. On the other hand, the Committee does not believe that the development of the non-engineer into an engineer is inappropriate, especially for the applicant who is strongly motivated or for the individual having a physical science background in mathematics, physics, or chemistry. We should perhaps be reminded that a baccalaureate degree in one of the sciences does not constitute an especially negotiable credential for a career in science. Here the Ph.D. is the only truly professional degree. Furthermore, for example, a B.S. in chemistry is in many respects better preparation for graduate work and a career in water quality management or air pollution control than the traditional civil engineering baccalaureate.

The second alternative would place in juxtaposition to the environmental engineering degree program an environmental science program. The science program and the engineering program should direct similar levels of students forward together, defining problems, studying research techniques, overlapping where possible, separating where prerequisites make overlap impossible, but intertwining at all opportunities to produce a group which would have a common language, a common problem orientation, and a common dependency on one another for advice and counsel in the area of special competence which each can bring to bear on the problem.

The Committee decided to first ascertain what trends were apparent in the field and how progressive schools around the country were seeking innovative solutions to the manpower shortage problem. The ASEE roster indicates that 174 schools offer civil engineering curricula. Of these, 98 were selected as having an above-average interest in the academic features of the sanitary and environmental engineering field. Because these schools represent a good cross-section of the total number and because they also probably reflect the most progressive attitudes in the field, they were chosen to be subjected to a brief survey.

The survey included questions concerned with the admission requirements to graduate programs in engineering and was designed to reflect opinions relative to traditional engineering curricula. For example, does a school: (a) Admit engineers only? (b) Permit non-engineers to enter their graduate programs, but require make-up of essentially all engineering prerequisites? or (c) Allow non-engineers to take an engineering degree with little in the way of engineering preparation? Further, do these schools have a mechanism by which non-engineers can enter engineering programs but receive degrees which do not specify engineering.

The response to the questionnaire was excellent, with 75 percent of the schools responding within two weeks. The survey indicated that there is a wide diversity of curricula and degrees available, though the traditional sanitary engineering program with little allowance for the non-engineer is still most prevalent. With regard to the kinds of degrees available the responses can be categorized as follows:

Group	Type Of Response	Number Of Schools Responding
1.	Engineering degrees only available	56
2.	Applied science degrees available	1
3.	Undesignated degrees available	5
4.	No advanced degrees available	2
5.	Both engineering degrees and science degrees available	10
		74

Those schools which specified undesignated degrees probably also offer the engineering degree, but misunderstood the questionnaire. Thus, Groups 3 and 5 should probably be placed together to represent about 20 percent of the respondents. Most of these programs (included in Groups 3 and 5 above) report their non-engineering degree programs to be one to five years old, and this change is believed to represent a distinct shift in attitude relative to traditional engineering programs which have in the past been offering only engineering degrees.

The Committee also attempted to ascertain the viability and success of these engineering based-science programs and was able to establish the following guidelines:

1. Non-engineering type courses (e.g., applied chemistry and biology) offered in engineering programs are probably best taught by non-engineering specialists emphasizing engineering applications and stressing real problems.
2. Teaching personnel involved in these programs must be made to feel accepted equally along with their engineer colleagues by their department and college administration. Academic attainment should, therefore, be measured by teaching excellence, research publications, and public service as applied to the engineer, but not on the basis of professional achievement in an engineering sense. Opportunities for advancement must be equal.
3. Non-engineering teaching personnel can probably best keep their own scientific capabilities at a peak by joint appointments with science departments, by serving on doctoral committees in their field, and by joint guidance of research of science students.
4. The satisfactory acceptance of the first three of these guidelines obviously establishes a healthy climate which will permit and encourage the extension of equal opportunities and status throughout the entire profession. This must be the ultimate goal for the success of the

engineering-science team within engineering departments.

While most of the schools surveyed showed a distinct interest in the non-engineer student, the survey indicated that about 60 percent of the respondents offer this non-engineer only an engineering degree. The reasons for this are not entirely clear, but the inertia of tradition and the fact that applied science education is still an academic no-man's land are probably the principal causes.

The Committee expressed concern for the integrity of the engineering degree and believed that it should be reserved for persons properly grounded in engineering fundamentals and exposed to the concepts of design and synthesis. Inquiry into the prerequisites for entrance into graduate engineering programs required by the respondents revealed the information shown in Table VI.

From these results it seems evident that chemistry, which is taken by many civil engineers as a one- or two-semester general chemistry course, is required by most programs. Calculus and fluids are, likewise, emphasized as prerequisites. Few of the programs required structures or transportation courses, and design was required by some and not by others.

TABLE VI
REQUIREMENTS OF SCHOOLS* SURVEYED FOR ENTRANCE INTO THEIR RESPECTIVE ENGINEERING GRADUATE DEGREE PROGRAMS BY NON-ENGINEERS

Topic	Same as Eng. BS	Less than Eng. BS	None
Calculus	45	8	0
Fluids	43	6	5
Structures	5	11	25
Transportation	3	4	26
Chemistry	51	0	2
Design	13	13	15

*Taken from a survey of 74 schools. In many instances the replies were unclear or this question was not answered.

The questionnaire was not field tested prior to use and undoubtedly could have been improved. However, its message seems clear. Colleges of engineering are changing slowly. They appear to find it difficult, or perhaps are reluctant to provide non-engineering degrees. Moreover, on this question the Conference did not agree that engineering colleges should offer non-engineering or applied science degrees. It may be concluded that freshman chemistry, freshman and sophomore mathematics, and a course in fluid mechanics are the most essential undergraduate prerequisites to graduate education in sanitary engineering.

If this conclusion is a correct assessment of contemporary academic opinion, it must be concluded that the lines between engineering and science have indeed been attenuated and that the professionally capable engineer cannot be identified solely by the fact that he holds an engineering degree. However, let there be no mistake regarding the fact that engineering analytical and design ability is still the essential quality by which the performance of the sanitary engineering profession will be judged.

On the other hand, it must be recognized that little need exists for the engineering-scientist specialist in air or water to spend time in the traditional design courses concerned with structures or transportation facilities. While the engineering student normally achieves some sense of the engineer's role through this route, those judgment factors which are developed, and which are largely specific for those particular fields of application, would obviously not be ideal for the environmental scientist.

CONCLUSIONS

1. There is a real need for the education of non-engineering specialists, such as the chemists, biologists, geologists, meterologists, and statisticians, for service in the environmental engineering field. As with the engineers, these individuals should be prepared to function within the specialty areas of environmental science, such as air, water, industrial hygiene, etc.
2. To provide such specialists the procedure might be to structure at some schools interdisciplinary graduate applied science degree programs, preferably closely associated with or in engineering departments.
3. If non-engineers are to be matriculated in programs leading to engineering degrees, they should complete the appropriate undergraduate preparation in the fields of mathematics, chemistry, fluid mechanics, and engineering sciences required of undergraduate engineering students who normally enter sanitary engineering curricula. Such students should also complete those engineering analysis and design courses required of undergraduates which are central or pertinent to the sanitary engineering or other graduate environmental engineering curricula.
4. Where non-engineers are to be given applied science degrees there is no need to require engineering courses of the same depth as given the engineer even though the degree program is administered in a college of engineering. However, there should be ample opportunity provided through interdisciplinary seminars and courses

suitable for both engineers and scientists for the process of cross-fertilization to occur and especially for the non-engineer to acquire some appreciation for the engineering approach. Recognizing that mathematics is the most common mode of expression among engineers and scientists, it is believed that non-engineers in applied science programs should be expected to complete the mathematics required of all physical science and engineering students.

5. Non-engineering faculty should be encouraged to join sanitary and environmental engineering staffs. They should at the same time maintain their contacts with their basic disciplines through dual appointments, seminars, research, and student advising.

VIII. CRITERIA AND MECHANISMS FOR ACCREDITATION OF PROFESSIONAL CURRICULA

The question of the desirability of accreditation of graduate programs has been debated at length even though the accreditation of first degree programs has existed for many years. The first graduate program in sanitary engineering was accredited in 1959, and by 1966 a total of 15 programs had received ECPD accreditation. An excellent review of the history and merits of accreditation was presented by Professor J. E. McKee in the *Report of the Study Conference on the Graduate Education of Sanitary Engineers* in 1960. McKee notes that the question for debate is whether sanitary engineering programs should develop in the pattern of professional schools, for which he believed that accreditation was inevitable, or whether they should remain under the aegis of the graduate school and thus be less likely to accept accreditation.

The advantages of the accredited program within a professional school is the greater likelihood that sanitary engineering and the other fields of environmental engineering will be recognized as truly professional and on a par with medicine and law. Perhaps the strongest argument presented by McKee for accreditation is that the frequent examination of the staff qualifications, physical facilities, and curricula of accredited schools will assure that these programs will become recognized as offering a superior professional education. Another advantage cited, but one sure to be opposed by those who hope to initiate programs with the assistance of federal funds, is that accreditation provides governmental and private agencies with a yardstick to measure the merit of schools to which they contribute. It is evident that accreditation may tend to create an *establishment*, or so it might appear, at a time when many in our society are questioning the established institutions.

Professor McKee's case for sanitary engineering within graduate schools assumed that accreditation would not be acceptable to or desired by the institution. He notes that in a graduate school, sanitary engineering (and presumably its associated environmental engineering specialties) would be recognized as an academic discipline, that doctoral candidates would be subjected to the same high academic requirements as in the sciences, and that innovations in curricular development would be encouraged, rather than restricted by outside control. On the other hand, we might argue that in some institutions accreditation of professionally-oriented master's programs administered by a graduate dean responsible for all graduate education is quite feasible and not necessarily inconsistent with either the concepts of graduate education or the role of the professional school. This has been the situation at Berkeley since the sanitary engineering program was accredited there in 1959. After all, external review of academic programs is desirable and in the final analysis only advisory.

Perhaps one of the most significant actions taken at the 1960 Conference was the unanimous approval of four resolutions concerned with accreditation. These are quoted as follows:

> "1. The ASEIB* should endorse the accreditation by ECPD of graduate programs in sanitary engineering, including other programs in sanitary engineering related to environmental health, beginning with master's programs.
> 2. To be accredited in sanitary engineering, including other engineering programs related to environmental health at the graduate level, (the program) shall not have to offer instruction in more than one of the fields considered by the Conference.
> 3. A resolution favoring these positions should be transmitted to ECPD.
> 4. The resolutions and recommendations of this Conference should be submitted to ECPD as guidelines or general criteria for the accreditation of suitable programs."

In June 1966 Dean H. B. Gotaas presented a paper on *Desirability of Accreditation of Graduate Programs in Engineering* at the annual meeting of the American Society for Engineering Education. He reported that in ECPD's 32nd Annual Report it was made clear that the policy was to accredit curricula leading to first degrees in engineering and that the accreditation of graduate programs was a matter of interim policy. The basis of accrediting graduate sanitary engineering curricula under this policy was that these were *first degree curricula* in a specifically named branch or area of engineering. However, Gotaas observed that accreditation of graduate programs in fields other than engineering has been increasing and that 20 fields had (in 1966) some form of accreditation. He concluded that the desirable aspects of accreditation outweighted the undesirable and commended the sanitary engineering profession for its active leadership in the movement for accreditation at the master's degree level.

The question of graduate program accreditation has been considered by the Committee on Goals of Engineering Education of the American Society for Engineering Education in both its Preliminary Report of October 1965 and the Final Report of January 1968. In the final report the Goals Committee recommends that during the next decade basic engineering education be extended to include at least one

*Now the Environmental Engineering Intersociety Board; EEIB.

year of graduate level education. Furthermore, it is recommended that the accreditation of programs beyond this level be postponed until such time that it is evident that a need exists. However, the Goals Committee favored a flexible accreditation program, one allowing accreditation at either the bachelor's or master's level, or both, either by general or special fields.

In many respects the professionally-oriented M.S. degree in sanitary engineering is a fifth year of basic engineering education, but in a specialty, following four years of preparation in science, engineering-science, and civil engineering. In some institutions it is possible to select elective courses in the senior year that become a part of the master's program, thus forming an articulated five-year civil-sanitary engineering curriculum. It would appear that in these situations the present Goals Committee statement would be in support of accreditation.

It is evident that the engineering education has moved away from the philosophy of sharply circumscribed professional areas, clearly separate from each other within engineering, and distinctly different from the sciences and social sciences. This changing attitude is reflected by the division of opinion regarding accrediting at the 1967 Conference of sanitary engineering educators compared to the unanimity favoring accrediting at the 1960 Conference of a similar group of educators. Why does the young engineering educator as well as many of his successful older colleagues look with such disfavor upon the concept of a profession and its sustaining accouterments? There is no single answer to this question, but among the many answers we might list: (a) the increasing input of science to all branches of engineering; (b) the increasing numbers of engineer-scientists who in the course of earning the Ph.D. degree identify themselves more with science and the scientist than with an established branch of engineering; (c) the federal monies supporting *basic* research in contrast to the almost total absence of funds for *applied* or professionally oriented research (this being especially true in the environmental fields); and (d) the recognition by the educator that nearly all engineering problems are multidisciplinary and that the traditionally educated professional engineer may not be sufficiently equipped to resolve them. The above comments apply largely to the educator; the attitudes of the consultants and other sanitary engineers nearer the *real world* of the profession will be discussed later in this chapter.

THE CASE AGAINST ACCREDITATION

The Conference Task Committee on Criteria and Mechanisms for Accreditation generally opposed accreditation and in their initial report recommended that the Conference reject ECPD accreditation for graduate programs and take more positive steps toward the improvement of education, rather than an approach based on *a negative, minimum standard, punishment concept of accreditation.* The portion of Professor McKinney's Committee report giving arguments against accreditation is presented in this section, while in the following section an alternate route to improved education in environmental and sanitary engineering is offered by the Committee.

> "The opponents of accreditation feel that accreditation is contrary to the basic concepts of professional education. If the educational community is truly professional and is willing to accept its responsibility, there is no need for accreditation. In fact, it has been stated that accreditation retards progressive development and tends to stifle creative programs through conformity to a basic educational program.
>
> "Current ECPD accreditation procedures are designed to set minimum criteria for course content, faculty and facilities. These procedures tend to produce a relatively uniform base for all programs having similar designations. Definite efforts are made to prevent criticism of specific faculty members. The net result is that ECPD accreditation tends to be either mechanically oriented or highly subjective without regard to details. While such accreditation procedures have been reasonably successful with moderately large programs of a uniform character, they cannot be applied to highly imaginative programs which depend upon the personal characteristics of one or two staff members. Graduate education is predominantly a personal interchange between an individual teacher and a few students who act essentially as apprentices. While such education lacks efficiency, it is the cornerstone of good graduate education and cannot be standardized by any accreditation procedures.
>
> "Environmental and sanitary engineering is a broad field which covers many topics and disciplines. It encompasses the best of chemistry, biology, physics, mathematics, engineering, business management, and the social sciences to solve the multitude of problems facing man and his environment. Graduates from the various programs fill a diversity of positions in consulting, in government, in operations, in construction, in sales, in research, and in teaching. To meet the broad spectrum of needs, we must have a multitude of programs with widely differing approaches. Such a wide scope of programs cannot be covered with a single accreditation program such as currently exists with ECPD.
>
> "The opponents of accreditation are opposed to the use of accreditation as a basis of allocating research and program funds from

the federal government. In their opinion allocation of federal funds in this manner is professionally unethical and contrary to the basic concepts of a free society. To them accreditation is one step towards the formation of a closed society in which a few schools will be rewarded no matter how productive they really are.

"To date accreditation is not a prerequisite for successful practice. Professional engineering societies have not felt that it is necessary to obtain accreditation of graduate programs. Least of all, the employers of the engineering graduates have not shown sufficient concern over current education to even express a desire for accreditation. Current efforts at certification of graduate engineers by the Environmental Engineering Intersociety Board have failed to produce any noticeable improvement in the status of Sanitary Engineers. The problem does not lie in either accreditation or certification but rather in the failure of the profession to recognize its own problems and to make an honest effort to solve those problems.

"There is no doubt that there is merit to the views held by both the proponents and the opponents of accreditation of graduate programs in environmental and sanitary engineering. No one will disagree that there is a need for continued improvement in education. Disagreement comes only as to the value of accreditation as the mechanism for improvement in graduate programs.

"There is considerable evidence that the current ECPD accreditation procedures cannot be applied meaningfully to meet the diverse needs of the field. One of the real strengths of the field lies in its flexibility to adjust to new technology and changing needs. Past experience with ECPD accreditation would indicate that accreditation would limit this flexibility and adaptability in some schools. To date such limitations have not occurred but it is believed that this is more due to the desire of a few individuals to insure that ECPD accreditation is established than to the mechanism of ECPD accreditation."

. . .

AN ALTERNATIVE TO ACCREDITATION

"The Task Committee on Accreditation does not feel that there are enough incentives favoring ECPD accreditation to warrant recommending it for graduate programs in environmental and sanitary engineering at this time. Yet, the Committee recognizes the need for establishing a mechanism for improving the quality of graduate education. The following suggestions are presented for consideration as one method for accomplishing this goal.

"Initially there is a need to provide a continuing forum for discussion of the common problems facing education. To date none of the existing professional organizations have seen fit to create such a forum. Unfortunately, existing professional organizations do not lend themselves to the establishment of an educational forum devoted entirely to the problems of environmental and sanitary engineering. Such a forum could be established similar to the University Council of Water Resources with each participating university having a single membership. In this way emphasis would lie with the programs and not with individuals. It would also insure that all schools would have an equal voice regardless of their size.

"The establishment of a University Council for Environmental and Sanitary Engineering would serve notice upon the engineering profession as well as upon the public that the educators are seriously concerned with the educational problems facing them and are moving in a concerted effort to help solve those problems. At the same time University membership would help consolidate local support at the University level behind each program. It would notify each university president and engineering dean that there was a single professional educational group speaking for the field. By proper demonstration of our responsibilities in this vital area it would be possible to gain the respect we desire. Too often we have sought improvement of status by decree and by degree rather than by action. The net result has been a failure to gain support or to solve any of the problems facing us.

"The prime purpose of the University Council for Environmental and Sanitary Engineering would be to focus attention on the key problems facing the profession and to suggest approaches for educating future engineers and scientists to meet these problems. It should act as a source of information on each program. Prospective students and other interested persons would be able to locate information on the areas of specialization, the faculty, the courses, the research, and the facilities of each participating program. Such information would form a basis of personal evaluation without the prejudice of an individual accreditation visitor. It would also serve as a comparative guide between programs and could be used to stimulate individual support at a particular university.

"It is hoped that the university council will examine the various programs annually or biannually, noting exceptionally strong programs as well as weak programs. In both cases the university council should make a strong effort to publicize the results of its studies. In this way strong programs could be rewarded and weak programs could be noted for improvement. It is expected that this positive approach would produce more substantial improvement in graduate education than can be obtained by ECPD accreditation which is negatively based on the minimum acceptable standards. The problem is not to destroy the weak but rather to raise all schools to the highest possible level. Only by taking a truly professional approach and making a positive, constructive effort to lift all programs can we possibly solve the problems we currently face and the future problems we must face."

ATTITUDES TOWARD ACCREDITATION OF SANITARY AND ENVIRONMENTAL ENGINEERING CURRICULA

In the closing session of the Conference a recommendation was made and unanimously approved by the conferees that the faculty of each program in sanitary and environmental engineering be requested to provide the Conference Steering Committee with a statement indicating whether or not it concurred in principle with the concept of ECPD accreditation of fifth year programs in environmental and sanitary engineering; and, if so, were they satisfied with the present mechanism of accreditation. Accordingly, a letter dated September 1, 1967, was sent to the head of each educational program listed in the 1966 *Register of Graduate Programs in the Field of Sanitary Engineering Education* requesting that the matter of accreditation be discussed with his faculty and that the consensus be reported to Dean L. G. Rich of the Conference Steering Committee by October 15. Copies of the three documents listed below were enclosed with each letter to assist in the deliberations of the faculty groups:

Qualifications for Accreditation of Advanced-Degree Curricula in Sanitary Engineering, ASEIB (now EEIB) Com. Sanit. Eng. Ed., 1963.

Accreditation of Curricula Leading to First Degrees in Engineering in the United States, Objectives and Procedures, reprinted from 33rd Ann. Rept. ECPD.

Instructions to Evaluators of Advanced-Degree Curricula in Environmental Engineering, ASEIB Com. Sanit. Eng. Ed., July 1966.

Fifty-seven letters were sent, and on November 7 a follow-up letter was sent to those that had not replied to the initial letter. By December 15 replies had been received from 46 of the 57 program heads contacted. The results are shown in Table VII, together with the faculty numbers and enrollment as reported in the EEIB-AAPSE register for the 1965-1966 academic year.

TABLE VII
RESULTS OF OPINION SURVEY ON ACCREDITATION OF MASTER'S PROGRAMS IN SANITARY AND ENVIRONMENTAL ENGINEERING

Response	Number Of Programs	Number Of Full-Time Faculty	Full-Time Enrollment M.S. Level	Full-Time Enrollment PH.D. Level
For Accreditation	20	124	265	162
Against Accreditation	22	86	206	77
Undecided	4	12	34	33
No Reply	11	50	101	68
Total	57	272	606	340

Although a slight majority of the programs were opposed to accreditation, a majority of the faculty continue to favor it. However, among the 20 programs favoring accreditation, only 11 indicated that they were satisfied with the present mechanism of accreditation.

Of the 15 accredited graduate programs in 1966, the faculties of two indicated that they do not favor the concept of ECPD accreditation of fifth-year programs. Thirteen of the 15 accredited programs were listed in the register. The average full-time faculty staff of these accredited programs was 7.2, as compared to 4.8 for the 57 schools listed. The average master's enrollment of the 13 register schools favoring accreditation was 17.6 compared to 6.6 for the total listed. These statistics only seem to confirm what might be expected—that the larger and long-established schools tend to favor accreditation, whereas the smaller and newer programs do not.

One of the more common objections of the questionnaire respondents to the present accreditation procedures was the inappropriateness of recommending that at least one diplomate of the American Academy of Environmental Engineers be on the staff of an accredited program. It was generally agreed that membership in an organization should not be a requisite for accreditation even though that organization's purpose was to recognize outstanding and qualified professionals in the field. In one instance a program head indicated that they would probably drop their accreditation unless this recommendation were changed. It is to be noted, however, that at least two programs have been accredited in which there were no diplomates on the faculty. The opponents of accreditation generally agreed that it would tend to stifle innovation in graduate education, that it discriminates against the small program seeking to become established and in need of external support, and that it might serve to set sanitary engineering apart from civil engineering at a time when there is little or no interest in accreditation among the other specialty areas of civil engineering.

Recognizing that the attitude of the educator toward professionalism is likely to differ from that of the practitioner, Dean L. G. Rich, in his capacity as chairman of the EEIB Education Committee, also sent letters of inquiry to sanitary engineers in industry, private practice, and government regarding their opinions of accreditation. The same documents were furnished to the practitioners as were given to the academicians. Of the 30 letters sent, all of the 16 replies favored accreditation, and, with one exception, all engineers replying indicated satisfaction with the present mechanism of accreditation.

CONCLUSIONS—RECOMMENDATIONS

It is evident from the facts presented herein that a wide spectrum of opinion exists in the academic sector of the sanitary and environmental engineering professions regarding the pros and cons of accreditation. No consensus was reached at the Conference at Northwestern University, and subsequent inquiry did not provide a basis for accepting or rejecting the concept of accreditation of the first professional degree in sanitary or environmental engineering. As noted earlier, the ASEE Goals Committee is facing a similar lack of consensus and has chosen to take a position supporting the *status quo, no accreditation of second or higher professional degrees in engineering.* The basis of ECPD accreditation of graduate programs in sanitary engineering is that it was the first professional degree in this field and as such constituted a fifth year of basic engineering education. As other engineering specialties adopt the fifth year of basic engineering, they may also extend their accreditation to include these programs.

The Conference Editorial Committee concludes that the accreditation of graduate programs in sanitary engineering as initiated in 1959 continues to be an experiment in graduate engineering accreditation. As an experimental effort, it cannot as yet be ruled a failure, yet until a similar course of action is adopted by other professional specialties within engineering it cannot be judged a success. The Committee therefore recommends that accreditation of professional master's programs in sanitary and environmental engineering continue to be available to those groups seeking such recognition.

The question of accreditation criteria and mechanisms can be answered in a more positive manner. Of the 46 schools replying to the questionnaire, only 11 indicated satisfaction with the present mechanism. Many of those who opposed accreditation in principle cited the criteria as arguments against the principle, while nearly half of those favoring the concept were not in agreement with the methods used to implement it. With due cognizance of the views expressed by the faculty of over 75 percent of the sanitary and environmental engineering programs canvassed, the Editorial Committee can only conclude that changes in accrediting procedures are indeed needed and that the success of this experiment in graduate engineering accreditation may well depend on the nature of these changes.

IX. GRADUATE CURRICULA FOR PROFESSIONAL AND RESEARCH CAREERS IN ENVIRONMENTAL ENGINEERING

INTRODUCTION

In today's complex and changing world, it is not surprising that the development and maintenance of the optimum educational experience for engineers charged with controlling the adverse impact of social and technological development is also a complex, transient, and often confused undertaking. Couple the natural forces of change with promotional or economic incentives to provide special educational experiences for particular and sometimes short-term objectives of special interest groups, and the problem is confounded by almost orders of magnitude. This is not to say that the influence of special interest groups on the development of educational programs is necessarily undesirable, but only that such forces do have a substantial effect on the development of educational programs at almost all institutions. The influence of federal support of contract research on the academic programs of many institutions has been both substantial and invaluable in the upgrading of facilities and staff. It is not unexpected that the character of research support would have a substantial impact on the pattern of educational programs, especially in an area as broadly defined as environmental engineering.

In an attempt to provide a basis for a critical and objective analysis of environmental engineering education today and a projection of what it should be in the future, it appeared prudent to the Committee on Graduate Curricula to assess the general character of existing educational programs in the field. It is recognized that each program has evolved in its own particular fashion, not necessarily as the result of precise curriculum design but largely as the result of historical development or tradition, the influence of a few strong individuals, institutional objectives and finances as well as direct extramural support. Within the practical limitations of available time, the Task Committee undertook a limited survey of the current curricula in 28 educational institutions with substantial ongoing programs. The list of institutions surveyed was not intended to be all inclusive; however, it was believed to be representative and it included the institutions represented by panel members of the Task Committees for this Conference.

TERMINOLOGY

Prior to discussion of specific curricula and their objectives, a few comments to clarify the terminology used may be in order.

For purposes of this report the Conference agreed that *environmental engineering* is a generic or *umbrella* term for the broad field of endeavor of which sanitary engineering is a part. It was also noted that although prior definitions of the term *sanitary engineering* included a broad spectrum of activity, the majority of sanitary engineers are in fact water quality (management) engineers. Such terminology and definitions are consistent with the data reported in the 1966 EEIB-AAPSE *Register of Graduate Programs in the Field of Sanitary Engineering Education*.

As discussed in Chapter I, an area of confusion exists regarding the terms *sanitary engineering* (water quality engineering) and *water resources engineering*. For purposes of this report the term *water resources engineering* is considered a generic term applied to all areas of water engineering in the broadest sense and within which the specialty areas of sanitary (water quality) engineering, hydraulic engineering, and hydrology are a part. Thus, a water resources engineer should first be either a sanitary engineer, hydraulic engineer, or hydrologist.

The term *air resources engineering* is used as a generic term including all areas of air resources engineering such as air pollution control (air quality management engineering) and the appropriate areas of meteorology. The air resources engineering field does not yet have the historical association with particular terminology, hence it does not appear to have as deep an aura of confusion associated with specific terminology as does water resources engineering.

The two other specialized fields of activity dealt with in the context of this report—radiological health and solid waste engineering—appear to be sufficiently defined so that questions of appropriate terminology are not significant.

FUTURE NEEDS

Before a critical appraisal is made of the ongoing educational preparation of environmental engineers, it might be advantageous to consider briefly some of the objectives and constraints for the education of the engineer of the future.

In addition to the rapid expansion and increasing complexity of problems of environmental control and management, there are several factors somewhat related which should be emphasized. First, the role of government in environmental control is expanding rapidly, and it will likely continue to expand with the support and insistence of congress and the public. Second, because of the increasing complexity of pollution problems of all kinds and the corresponding gross increase in expense to the taxpayer for acceptable solutions, the real world of practical economics will require that increased attention be given to problem investigations to insure optimum solutions. Such analyses will be aided by the judicious use of systems analysis, operations research techniques, and computerized data processing and analysis. Third, attendant with the increased public concern and funds for environmental pollution management is a marked increase in the number of professional and scientific organizations and individuals active in the area of environmental pollution control. Notable examples are the substantial efforts and activities of several of the giants of the aerospace industry engaged in projects ranging from composting and solid wastes management to estuarial pollution analysis and reverse osmosis demineralization.

It has been pointed out in Chapter I that there have been marked changes in the character of consulting engineering practice during recent years. The conduct of special studies and investigations, even including substantial amounts of applied research and development, constitutes an increasing amount of the consulting engineer's time as compared to a decade or two ago, when his work was largely the production of designs and specifications, often of a routine nature. In the future, however, (and in many instances even today) it seems evident that the consulting engineer will require a greater depth and breadth of scientific capabilities as well as advanced levels of specialized engineering technology. In the chapters of this report devoted to specialized areas, such as biology, chemistry, and systems analysis, it is concluded that the environmental engineer needs more of each to acquire adequate educational expertise to meet the challenge of the future.

How can such goals as the foregoing be accomplished within the framework of modern educational systems? It appears that the only answer is more education for both professional practice and research. Traditionally, at least within the sanitary engineering profession, the fifth year or master's degree level of educational experience was the terminal degree for individuals planning to enter professional practice, be it in government, industry, or private practice. Correspondingly, the doctorate was considered largely for those desiring to pursue a career in research or education. Today, increasing numbers of doctorate-level engineers are going into industrial and consulting practice, and there appears to be little doubt that this trend will increase markedly in the future.

DEGREES

Master's Degree

From the pattern of engineering education today it seems evident that the fifth year, or master's degree levels in environmental-sanitary engineering should be the *minimum* educational requirement for essentially all types of professional practice. This level of education is necessary if the engineer-practitioner is to maintain a position of leadership in the field and is requisite for practitioners ranging from sales engineers or representatives to designers. Designers, in particular, should have the benefit of the master's level of education if optimum functional design solutions are to be produced and they are to be current with advances in other sectors of our technology.

Educational emphasis at present seems directed more to science than to engineering practice. Of the 28 institutions included in the Committee's survey, 27 institutions (96 percent) offered master of science degrees, whereas only 11 of the 28 institutions (39 percent) offered the master of engineering degree. Moreover, of the 10 institutions offering both degrees, only one institution reported more individuals pursuing the master of engineering than the master of science degree. However, here it must be recognized that graduate education began with the sciences and that in an engineering school today the science degree designation (i.e., the M.S.) does not preclude the offering of substantial amounts of engineering oriented course work as part of the degree requirement.

Considering both the wide diversity of program objectives as well as subject-area emphasis in the institutions surveyed, it is surprising to note the relatively minor emphasis on the master of engineering degree. If the master of engineering degree is to be offered, it would appear advisable to offer this degree for those programs oriented to a terminal professional curriculum, including the engineering systems-economic area. If the engineering degree is to be enhanced in stature, programs of study leading to both the master of science and master of engineering should be available. Moreover, if there are any significant differences in the requirements for the degrees, the difference should be in the direction of increasing the requirements and stature of the master of engineering degree.

Doctor's Degree

One of the current trends noted in the survey of educational programs as well as reflected in the recommendations in Chapter I is toward strengthening the engineering-systems analysis-economic base for doctoral programs in environmental engineering.

A corollary trend is noted in the tendency to offer doctorates in broad engineering areas (such as water resource engineering) as compared to the traditional science-oriented Ph.D. programs. Possibly one justification for the foregoing indicated trends is the increasing number of doctoral level engineers going into private practice. Chapter I of this report, as well as the findings of the survey conducted by this Committee, indicates clearly that consulting engineering organizations are engaging in an increasing percentage of investigative and research and development work. That such activity requires personnel of a different level of educational sophistication than the traditional design function is evident. This trend is also reflected in the rapidly increasing number of doctoral level engineers engaged in consulting engineering. Citing one example does not prove a rule; nevertheless, it is of interest to note that one institution reported that its three most recent doctoral degree graduates were employed in consulting engineering practice. Moreover, a senior partner of a leading consulting engineering firm stated specifically that *we cannot call a man a sanitary engineer unless he has the equivalent of what we now get in a Ph.D. degree program.*

It appears that a marked shift in demand and opportunity for doctoral level sanitary engineers is occurring. In the recent past the great majority of doctorates produced in this field were absorbed by the academic institutions for teaching and research positions. If in the future an increasing number of doctorates enter industry and private practice, the degree programs should recognize some of the legitimate needs of the professional practitioner. It would appear that greater emphasis should be placed on the engineering economics-systems analysis areas as contrasted with considerable depth in rather narrow science-oriented areas. It is recognized that the engineering doctoral program might have emphasis different from the Ph.D. program; however, in many situations the differences may be slight.

If it is accepted that in the future there should be two types of doctorate programs—mainly the science-oriented doctor of philosophy degree and also the practice-oriented doctor of engineering degree—a marked change will have to occur in the institutional degree granting structure. Of the 28 institutions surveyed, 26 offer doctor of philosophy degrees under programs having a wide variety of designations, ranging from public health and environmental health engineering to water resources engineering. Only 3 of these 26 institutions offer both Ph.D. and Eng.D. degrees. Moreover, it appears from the available data that only 1 of the 3 institutions routinely awards more Eng.D. degrees than Ph.D.'s. It is believed that questions regarding the designation and requirements for doctoral level degrees in the environmental engineering field need a critical review if educational institutions are going to meet successfully the needs of the profession for more and better educated engineering practitioners. The urgency for reevaluation of doctorate degree programs is underscored by the increasing pressure to provide a broader educational base without sacrificing competence in depth. There is a critical need for the engineering profession to enhance the prestige of its members as well as to improve its image, and to identify the appropriate function of the Eng.D. and Ph.D. degrees and the nature of the academic programs leading to them.

ONGOING PROGRAMS

The Committee on Graduate Curricula recognized at the outset that the simplistic approach would be to agree on compromise curricula based upon the experiences and programs at the member institutions. As the Committee deliberated it also became apparent that each individual questioned could stipulate the *best* educational program for any rational set of objectives. What soon became obvious was the great lack of specific information about degrees at institutions offering programs in all or selected areas of environmental engineering.

An excellent effort in developing specific information about educational programs in environmental engineering was the development of the AAPSE-EEIB Register of Graduate Programs, previously cited. As noted in the analysis of data by the authors of the register, the major deficiencies in the register were concerned with the lack of specific information to identify program strengths, weaknesses and requirements. Also, the need was indicated for degree course requirements and the normal (50 percent or more) courses taken for each degree. Such information would indicate the actual emphasis and character as well as the objectives of each degree program.

An attempt was made by this Committee to obtain information on course requirements and on the greater-than-50-percent elective courses for each of the degree programs. It was recognized that the data would not be complete; but, even limited information would provide a better basis for factual study and analysis than is possible with available information. The survey was relatively successful as most institutions polled provided the information requested. One component of the survey which yielded particularly interesting results was a questionnaire sent to a substantial number of former professors in sanitary engineering who are now eminently successful in the consulting engineering business. The former-professor consulting engineers were polled as to what changes they thought should be made in existing degree programs and this will be discussed later in the chapter.

MASTER'S DEGREE

As noted previously, 27 of the 28 institutions polled offer master of science degree programs in the general area of environmental engineering. One institution offers only a master of engineering degree, and 10 institutions offer both master of science and master of engineering programs. However, in several instances the differences in the two degree programs were slight.

Program-Degree Designation

Of the 26 institutions responding to this question, about two-thirds (15) of the institutions designated their program and/or degree with the term sanitary engineering. Eight of the institutions identified their program name with the word environment used in a variety of ways (bioenvironmental engineering, one; environmental systems, one; environmental health engineering, three; environmental engineering and science, three). Four of the institutions included the term water resource engineering along with sanitary engineering and in only one instance in conjunction with another term.

It is of interest to note that generally the degree (or graduate school curriculum if an unspecified degree is used) bears the same name as the program; however, in the exceptions observed (three), the degree area was still identified as sanitary engineering, whereas the program title was more broadly designated.

Units

The number of required semester hours for the master's degree ranged from an undefined number (three institutions) to a maximum of 36 units (two institutions). The mean number of semester units required was 31, and the median was 30. The lowest number of required units in a degree program was 24.

Thesis

A thesis was required for partial fulfillment of the master of science degree program at less than one-third of the institutions (eight) polled; however, four institutions required from 2 to 8 units of a special problem or project (individual study or research).

Degree Program Titles

One interesting characteristic of the information developed from the survey of the 28 institutions is the widely variable terminology used to describe educational programs. It appears that the only rational way to compare educational programs and their objectives is by examination of the curricula that the majority (50 percent or more) of the students follow.

Specific degree programs were often given designations that had little relation to the title given the educational program or to the name of the degree. Terminology, such as areas of specialization, specialties, major program areas, programs, technical areas, and options, was used often to indicate areas of emphasis in degree programs. For purposes of this report a degree program or curriculum was considered an entity when the educational institution identified a group of core or required courses plus recommended electives under a specific program title. In many instances, several programs were designated as specialty areas, all of which qualified under a single-degree designation. Thus, individual specialty programs generally do not have official degree or curriculum status, but represent a logical combination of courses in a particular area which is acceptable for a degree in a broad subject area such as environmental engineering or traditionally sanitary engineering. Such a procedure appears somewhat deceptive as the degree designation implies a broad subject area but the actual degree program followed may be rather narrow or highly specialized.

All 28 institutions surveyed offered a water and waste oriented program which was most frequently (16 out of 28 or about 57 percent) described by a sanitary engineering program title and/or degree designation. Possibly a more appropriate descriptive title for these programs would be water quality (management) engineering. The next most frequent program title used was water resources engineering, which was offered alone or in combination with sanitary engineering at 9 of 28 institutions (about 32 percent). Specialty degree programs in radiological health and air resources engineering were offered only at 5 institutions (about 18 percent). The only other specialty degree program offered by more than one institution was solid waste engineering, which was offered at two institutions. Specialty programs identified as bioengineering, water chemistry systems analysis, and design were offered only at one institution. It should be emphasized that, even though a specialty program in a given area was not identified at a given institution as such, this does not mean that one or possibly several courses in that area are not available at that institution.

It is apparent that a wide range of terminology is used to designate degree programs in environmental engineering.

Because of the difficulty in determining the actual character of a degree program from its title, an analysis was made of the survey information as to the

TABLE VIII
CHARACTER OF MASTER'S DEGREE PROGRAMS IN SANITARY ENGINEERING TAKEN BY MOST STUDENTS AT THREE SELECTED INSTITUTIONS AND PROGRAM CHARACTERISTICS AT TWENTY-TWO INSTITUTIONS*

Institution	Semester Units Required	Thesis Required	Percent of Program Devoted to Each Area						
			Water & Wastewater Engineering			Chemistry	Biology	Other Required Areas	Elective
			Theory	Lab	Design				
Selected Institutions									
California, Berkeley	24	No	33	17	0	33	17	0	0
Texas, Austin	30	Yes	20	10	10	10	10	10	30
Washington, Seattle	27	Yes	23	8	8	10	8	31	12
22 Institutions									
Mean	30		29	4.6	6.3	15.2	14.3	15.5	15.0
Maximum	36		63	17	20	38	42	44	52
Minimum	24		10	0	0	0	0	0	0

*Subject areas taken by more than 50 percent of all students pursuing M.S. degree. Note that a zero entry does not imply that students take no courses in that area or that students are not allowed to take electives. In all programs all of the students take some electives.

general composition of the degree programs at each institution. To insure adequate definition of each degree program, analyses were made of the core or required courses. Furthermore, each institution was asked to identify the specific subjects that the majority (50 percent or more) of the students complete for each degree program. These data were interpreted as accurately as possible, and courses were grouped in subject areas for convenience in tabulation. Liberal use was made of current catalog description of courses to ascertain the appropriate categories for each course listed as taken by most students.

Sanitary Engineering

Table VIII reports a summary of the composition of the master's degree program in sanitary engineering taken by the majority of the students at three of the institutions surveyed; plus the mean, maximum, and minimum values for 22 of the 28 institutions surveyed. Data from six institutions were omitted from the calculation of the means and boundary values because of inadequate information for such an analysis. The three schools selected show a distribution of emphasis in the various subject areas.

The subject areas for identification and examination were water and waste engineering subdivided into primarily *theory* courses, *laboratory* courses in unit operations and processes, and essentially *design* courses. The other categories used were chemistry, biology, other *required* subject areas (taken by 50 percent or more of the students) and electives. In the latter context the elective heading means only those electives that are taken by less than 50 percent of the students and thus cannot be classified in the other required course area.

Several points may be noted from the data presented in Table VIII. Most programs are heaviest in water and waste engineering *theory*, and lightest in *laboratory* experience with unit operations and processes of water and waste treatment. Coverage of *design* in formal design courses is also low, receiving only about 6 percent of the unit effort. The areas of chemistry and biology receive about equal emphasis (14 to 15 percent) from the majority of students, and the students have an equivalent amount of highly elective courses (taken by fewer than 50 percent of the students). There appears to be a wide range of subject emphasis among the institutions, some of which may be expected. It also appears that a range from 10 to 63 percent of student effort devoted to the engineering theory of water and waste management is more than might be reasonably expected and it is likely not representative of the actual situation. Although the Committee on Graduate Curricula interpreted the information supplied as consistently and as logically as possible, considerable error in interpretation is likely.

Water Resources Engineering

Table IX reports mean, maximum, and minimum percentages of effort devoted to each of 14 subject or course categories for the nine institutions reporting programs in water resource engineering. Again, the most notable feature of the analysis is the wide variability of programs and subject emphasis. At one institution, 42 percent of the program effort was devoted to the hydraulic-fluid mechanics area, whereas none of the other 8 institutions devoted any effort to this area. Another important feature of the reported programs is the breadth of subject matter considered a necessary part of water resources engineering by some institutions and the relatively narrow character of the program at other institutions. Such variation in program character may be the result of staff capabilities; however, part may also be due to the lack of adequate definition given to the objectives of water resource degree programs and of the professional area.

TABLE IX
CHARACTER OF MASTER'S DEGREE PROGRAMS IN WATER RESOURCE ENGINEERING TAKEN BY MOST (50 PERCENT OR MORE) STUDENTS AT NINE REPRESENTATIVE INSTITUTIONS*

	Percent of Program Devoted to Each Subject		
	Mean	Maximum	Minimum
Hydrology Geo. Hydrol.	10.6	31	—
Hydraulics Fluid Mech.	6.9	42	0
Water Quality	4.1	10	0
Water & Wastewater Treatment	9.0	25	0
Pollution Control	9.3	25	0
Res. Planning System Anal.	12.4	36	0
Chemistry	9.3	42	0
Biology	3.8	17	0
Economics	5.2	20	0
Economic Anal. + Planning	3.2	12	0
Pol. Science Institutions	0.9	7	0
Law	0.4	4	0
Other	17.3	43	0
Electives	6.8	21	0
Required Semester Units	—	69	24

*Cornell, Florida, Iowa State, North Carolina, Rensselaer Polytechnic Inst., Stanford, Texas, Univ. of Washington, Univ. of Wisconsin.

Air Resources Engineering

Table X presents a similar tabulation of the subject area emphasis pursued by the majority of students majoring in air resources engineering at the five institutions offering programs in this area. Several observations may be made from the data reported for the air resources engineering programs offered by the five institutions. There appears to be reasonable agreement (or availability of courses) as to what emphasis should be given to the several subject areas. The data indicate that an air resources engineer needs little, if any, educational exposure to the water and wastewater field.

TABLE X
CHARACTER OF MASTER'S DEGREE PROGRAMS IN AIR RESOURCES ENGINEERING TAKEN BY MOST (50 PERCENT OR MORE) STUDENTS AT FIVE REPRESENTATIVE INSTITUTIONS*

	Percent of Program Devoted to Each Subject Area		
	Mean	Maximum	Minimum
Required Sem. Units	29.4	36	24
Air Pollution Engineering	22	33	7
Meteorology	7.4	11.0	0
Chemistry	13	20	7
Water Waste Engineering	5	10	0
Other	15.6	35	0
Electives	37	59	13

*Florida, New York Univ., Oregon State, Texas, Univ. of Washington.

Radiation and Hazard Control Engineering

Table XI presents a summary tabulation of the distribution of effort of the majority of students pursuing programs in radiological health in engineering oriented programs. As with previous curricula, there is great variation in program emphasis. Except at one institution, it appears that a radiological health engineer has relatively little need for education in the water and waste engineering area. This appears somewhat surprising considering both the evolution of the radiological health field as well as the activity in radiological monitoring of the environment of which water and waste constitute a substantial part.

TABLE XI
CHARACTER OF MASTER'S DEGREE PROGRAMS IN RADIATION AND HAZARD CONTROL ENGINEERING TAKEN BY MOST (50 PERCENT OR MORE) STUDENTS AT FIVE REPRESENTATIVE INSTITUTIONS*

	Percent of Program Devoted to Each Subject Area		
	Mean	Maximum	Minimum
Required Sem. Units	26	30	24
Rad. Health Engrg.	18.2	40.0	8.0
Radiation Safety Hazards	6.6	17.0	0
Biophysics or Medical Physics	8.8	25.0	0
General and P. Chem.	11.4	18.0	8
Nuclear Chemistry At. Physics	9.8	18.0	0
Nuclear Eng.	1.8	9.0	0
Gen'l Environ'l Eng.	12.8	22.0	7
Water & Wastewater Eng.	5.4	19.0	0
Other	11	23	5
Electives	14.2	35.0	0

*Includes Florida, Iowa State, Rensselaer Polytechnic Inst., Texas, and Univ. of Washington.

DOCTOR'S DEGREE

The survey of degree programs at the 28 institutions was also intended to obtain data on doctorate course programs for each degree area. Unfortunately, the apparent combination of insufficient definity in the information request sent to the institutions and collation of the requested information on course sequences taken by most students resulted in a minimum amount of specific information about doctorate programs. The relatively limited data provided on doctor's degree programs were in sharp contrast to that provided on the master's program and were insufficient to make a meaningful analysis of the character of doctorate programs.

As pointed out previously, the most surprising information gleaned from the results of the survey was the very limited use of the doctor of engineering degree.

Significant variations occur in the number of languages required (1 or 2) and the extent to which minor areas are identified and given some specific requirements.

It is believed by this Task Committee that a detailed survey should be made of the character of doctorate programs in environmental engineering not only for evaluation of what is offered by the selected institutions but also for establishing a basis for critical appraisal and evaluation.

FORMER PROFESSOR-CONSULTING ENGINEER COMMENTS

A modest effort was made to obtain the counsel of a select group of individuals, all of whom were at one time professors of sanitary engineering and are now successful and prominent consulting engineers. It was surprising to note how consistent most of the comments were regarding what is needed to improve sanitary engineering education and the profession. A few highlights from these comments follow.

1. There should be more emphasis placed on the basic theory of processes in nature and treatment plants than in courses in design.
2. Sanitary engineering has too often been taught largely as a *cookbook* design subject.
3. There are too many sanitary engineering programs and teachers and not enough sanitary engineering practitioners.
4. Too many sanitary engineering teachers are theorists and not enough are practicing engineers. All young teachers should be urged to obtain, as a minimum, some part-time experience in engineering practice.
5. More emphasis should be placed on the basic sciences including physical chemistry, biochemistry, and general biology.
6. More attention needs to be given to economic analysis and the integration of theoretical principles with design practice.
7. The sanitary engineering profession has overemphasized academic coverage of public health disciplines and biosciences at the expense of advanced mathematics and fluid mechanics.
8. Greater emphasis needs to be given to the techniques of operations research and systems analysis as well as to advanced economic analysis.

9. A competent sanitary engineer today in practice needs the equivalent of a doctoral level education.

Most of the comments provided by the consultants are timely and appropriate. The real question is: How can all of these changes and objectives be realized? It appears that professors need more contact with the real world and the practice of their profession, and the consulting engineer practitioner needs the equivalent of the doctorate level of education. Hopefully, in the future both of these goals can be reached more nearly than at the present time.

RECOMMENDATIONS

1. A concerted effort should be made by the environmental-sanitary engineering profession, and particularly by the educators, to develop quantitative descriptions of the ongoing master's and doctor's degree programs at each institution. This is a logical extension of the AAPSE-EEIB register and was in fact recommended by the authors of the register.
2. AAPSE and EEIB should attempt to clarify and sharpen the terminology used to describe the environmental engineering areas.
3. The fifth year or master's degree level of education should be the *minimum* level for entry into essentially all types of environmental engineering practice.
4. A substantial study needs to be undertaken of the appropriate roles of the master and doctor of engineering degrees in modern engineering education. Such a study should include the objectives, scope, and character of the degree programs needed to enhance not only the engineering practitioner but the entire engineering profession.
5. The doctor of engineering degree is the appropriate degree for programs that emphasize engineering systems analysis and it should normally be the degree program for persons planning to enter professional practice. Programs of this type should increase markedly the application and sophistication of systems analysis and operations research tehniques to environmental problems.
6. Designers of modern degree programs, such as the doctor of engineering degree, should give serious consideration to the needs of private practice and professional engineering.
7. A recommended balanced curriculum leading to the master of science degree in sanitary engineering (i.e., water quality management engineering) should have approximately the following coverage of subject areas.

Area	Percent of Effort Required
Engineering	
Theory	20
Lab (Unit op. & Process)	20
Design	10
Chemistry	15
Biology, Microbiology	15
Systems Analysis, Statistics, Math, Econ.	15
Electives (Free)	15
	100

8. The first water resources engineering degree should be at the doctor of engineering level; or, as a compromise, at the level of the engineer degree as formerly awarded at many institutions. The water resource engineer should have educational competence in depth in a key area such as in sanitary or hydraulic engineering plus broadening education in the relevant subject areas. The emphasis in doctoral course work would depend upon the first (M.S.) degree of the individual, but in all cases it should include reasonable coverage of statistics, systems analysis, economics and economic planning, political science, and institutions, and the law, in addition to the sanitary, hydraulic, and hydrology areas.
9. A master's degree curriculum in air resources engineering might have approximately the following distribution of academic effort.*

Subject Area	Percent of Effort Required
Air Pollution Engineering	25
Physics	10
Meteorology	10
Environmental Health	10
Chemistry	10
Biology	10
Systems Analysis, Math, Statistics	10
Social Sciences or Electives	15
	100

*This particular recommendation was not considered by the Conference.

10. AAPSE and EEIB should review periodically the various degree programs (including the doctorate) at the institutions engaged in environmental engineering education and should publish its considered judgment as to the appropriate distribution of educational effort in each of the specialty degree programs. Such review and analysis of education in this field would do much to improve the programs at all institutions as well as to add quality and stature to the entire profession.

APPENDIX A
SUMMARY OF FINAL SESSION

Professor G. A. Rohlich, Chairman of the Conference Steering Committee, opened the final session and briefly outlined the procedures that would be followed by the Steering Committee and Task Committees in preparing the final Conference report. He asked that any statement related to issues raised at the Conference that had not been offered during the Conference sessions be sent to him prior to September 15, 1967. The Task Committee chairmen, working with their Committee members and liaison members from the Steering Committee, were to submit revised reports of their Committees to Professor Rohlich by November 15, 1967. These reports will include the edited notes of the session reporters. The individual Task Committee reports will be further revised so as to conform to a single format designed by Professors Rohlich, Rich, Gotaas, and Kaufman, who are to serve as an Editorial Committee. When this revision has been completed a draft of the full report will be distributed to the Task Committee chairmen for final review by their Committees.

Session I—*The Role of the Engineer in Environmental Engineering*

Professor E. F. Gloyna submitted two recommendations for consideration by the Conference:

1. "Recognizing that few individuals will be capable over the full breadth of Environmental Engineering as defined by the Environmental Engineering Intersociety Board and noting that the Academy has recently changed its designation from sanitary engineering to environmental engineering, it is recommended that the Conference adopt the term *Environmental Engineering* as the generic base of (a) Sanitary Engineering, (b) Industrial Hygiene Engineering, (c) Air Pollution Control Engineering, and (d) Radiation and Hazard Control Engineering."

Professor Gloyna stressed that the four areas of environmental engineering are the current specialty designations for certification in the American Academy of Environmental Engineers. In making the recommendation there was no implication that the Conference was being asked to endorse any particular set of preferred designations, but rather that it recognize the specialty areas in the broad field of environmental engineering. The suggestion was made that water quality engineering replace sanitary engineering in the recommendation. A motion was made and seconded to this effect, but it was defeated, receiving only two affirmative votes. A motion was made and seconded that the initial recommendation be adopted by the Conference and was passed with two dissenting votes.

2. "It is recommended that the report of Session I, following inclusion of the reporter's record of comments made from the floor, be adopted for inclusion in the final report with editorial changes as appear appropriate."

An extended discussion ensued regarding the nature of the editorial changes likely to be made. It was suggested by one member of the Conference that water quality engineering and sanitary engineering not be expressed as synonymous terms in the final report. It was observed by Professor Rohlich that in order for the final report to be a coherent and significant document, the changes will probably be greater than those normally associated with simple editing. It was moved by Professor Sproul and seconded that the Steering Committee be delegated the authority of expressing in the report the sense of the Conference. The motion passed unanimously.

Session II—*Scope of Environmental Engineering*

Dr. H. P. Kramer recommended that the report of his Committee be accepted by the Conference and the Steering Committee for further editorial review. Dr. Kramer then presented a recommendation to the Conference that defined environmental engineering as follows:

"Environmental engineering is that branch of engineering that involves the application of scientific principles to the prevention, control, and management of environmental factors that may influence the physical and emotional health of man and his well being."

A motion was made, seconded, and passed that the recommendation be adopted by the Conference. Dr. Kramer raised a question regarding the frequency at which such conferences should be held. He also suggested that the profession was at a point in time where a manpower study was needed and that such a study might be undertaken jointly by AAPSE and EEIB.

Session III—*Chemistry in Environmental Engineering Curricula*

Dr. T. E. Larson, after indicating that the first course in chemistry had been restructured based on discussion occurring during Session III, recommended that the report of his Committee be accepted by the Conference. The subsequent discussion focused on the desirability of specific and quantitative recommendations for required chemistry courses. Professor Quon suggested that the minimum chemistry required for the master's degree should be such as to permit it to be offered in several courses rather than to require it in a single sequence of chemistry courses. Professor Linsky agreed on this point and urged that it be explicitly incorporated in the final report. Professor Christman expressed reservations as to whether the objectives of offering a sequence of basic courses in chemistry, in which the individual subjects would appear in several process engineering and water pollution control courses generally not taught by chemists, could be met by the topical approach suggested by Professor Quon.

It was moved and seconded that the report be accepted by the Conference in principle and the motion passed unanimously. As was evident for nearly all of the Task Committee reports, their final form must reflect the sense of the Conference, the expertise of the Task Committee members, and the skill and forbearance of the Editorial Committee in fairly presenting the full scope of opinion expressed at the Conference.

Session IV—*Biology in Environmental Engineering Curricula*

Dr. R. A. Oglesby recommended that the Conference endorse his Committee's report as an interim effort. He also offered three specific recommendations:

1. "All environmental engineers should acquire a basic understanding of biological form and function and the interactions of living systems through appropriate required course work."
2. "Undergraduate students in engineering should be given the opportunity and encouraged to take fundamental courses in the life sciences."
3. "Curricula for biologists in environmental engineering programs should be encouraged and should include such chemistry, engineering, and especially designed courses in biology that acquaint the student with the general nature of the fields of environmental engineering. However, greatest emphasis should be placed on developing the biologists' skills and knowledge in the applied life sciences."

The question was raised whether a fundamental course should be required of all students in all sectors of environmental engineering. Although no consensus was evident, the motion to accept the report subject to further review was passed unanimously by the Conference. It was also observed that whereas it was desirable for all engineers to be exposed to the life sciences in their undergraduate education, the competition of the many disciplines and professional subjects, together with the practical considerations of curriculum design, mitigate against a biology requirement at the undergraduate level.

Session V—*Social Sciences in Environmental Engineering Curricula*

Professor R. O. Sylvester presented a summary of Session V and noted that his Task Committee had yet to complete their report. In order to obtain the sense of the Conference he asked whether the inclusion of a required course dealing with the social sciences was considered appropriate. Professor Sylvester indicated that the areas of principal emphasis in a special course for engineers would be resources economics, planning, institutions, and law. The vote clearly indicated an affirmative consensus to the question.

Session VI—*Planning of Environmental Systems*

Dean H. B. Gotaas moved that the report of his Committee be accepted by the Conference. The motion was seconded and passed unanimously.

Session VII—*Non-Engineering Students in Environmental Engineering Programs*

Professor B. B. Ewing presented three recommendations derived from the report of his Committee.

1. "There is a real need for non-engineering specialists, such as chemists, biologists, geologists, meteorologists, statisticians, etc., in the field of sanitary engineering and in the other fields of environmental engineering. To provide such specialists a solution would be to structure in as many schools as appropriate interdisciplinary graduate applied science degree programs; preferably, closely associated with engineering programs."
2. "If non-engineers are to be matriculated in programs leading to engineering degrees, they should be required to take or to demonstrate competence in essentially all of the undergraduate courses normally completed by engineers entering graduate programs in sanitary engineering. These would include the mathematics and chemistry taken by engineering students and the fluid mechanics and design courses underlying graduate work in sanitary engineering."
3. "Where non-engineers are to be granted degrees not specifying engineering, there is no need to require courses of the same depth as those taken by the engineering student even though the degree program is administered in the college of engineering. However, it is important that the non-engineering student be exposed to the philosophy of the engineer critical in the investigation, design, and operation of environmental control systems."

Professor Ewing stressed that students from the sciences should not be discouraged from taking an engineering degree by excessive undergraduate course requirement unrelated to the area pertinent to the degree. On the other hand, if the degree is one in the applied sciences (e.g., water chemistry) engineering course requirements should be minimal.

A motion was made, seconded, and passed that the recommendations be accepted by the Conference.

Session VIII—*Graduate Curricula for Professional and Research Careers in Environmental Engineering* (cf. Chapter IX)

Professor E. R. Baumann presented the summary and recommendations of this session. He indicated that major revisions would be made in the data presented in the initial report. The individual recommendations were then presented to the Conference.

1. "A concerted effort should be made by the environmental engineering profession, and particularly by the educators, to develop on a regular basis quantitative descriptions of the ongoing master and doctoral programs at each institution. Major effort should be expended by our profession to clarify and sharpen the terminology used to describe the fields within environmental engineering."

This recommendation, as set forth above, was approved unanimously by the Conference.

2. "The master's degree or equivalent education should be the minimum level for entry into essentially all fields of environmental engineering practice."

This recommendation generated considerable discussion. Professor Herman raised the question of whether such a recommendation would influence the certification criteria of EEIB. Professor Hanes pointed out that only the top 25 or 30 percent of the B.S. graduates are eligible for graduate work, and thus a majority of the bachelor's degree recipients would not be permitted to enter the field. A motion was made and seconded that the recommendation be accepted by the Conference. The motion carried by a narrow margin, insufficient to meet the two-thirds majority stipulation of the chairman.

3. "A substantial study needs to be undertaken of the appropriate role of the master and doctor of engineering degrees in modern engineering education. Such a study should identify the objectives, scope, and character of the degree programs needed to enhance the practice of environmental engineering in all of its areas."

This recommendation was passed unanimously by the Conference.

4. "The environmental engineering profession should hold more frequent conferences, preferably at not more than three-year intervals, to consider problems, goals, and programs in environmental engineering graduate education."

The preceding recommendation was made as a motion, seconded, and was passed unanimously.

Session IX—*Criteria and Mechanisms for Accreditation of Professional Curricula* (cf. Chapter VIII)

Professor R. E. McKinney presented two recommendations for consideration by the Conference:

1. "Each school actively offering graduate degrees in environmental engineering should be sent the ECPD Criteria for graduate education in environmental engineering and be requested to discuss the desirability of accreditation with all staff members and to submit as soon as possible their opinion. The results of the survey should be transmitted to all schools, to AAPSE and to EEIB and should be incorporated in the final report."

The above recommendation was offered as a motion, seconded, and passed by the Conference with four dissenting votes.

2. "A continuing body on environmental engineering education should be established by the Conference. The continuing or permanent group would be concerned with the delineation and improvement of educational criteria. The group should be representative of all schools having active graduate programs and should be known as the University Council on Environmental Engineering Education."

It was repeatedly pointed out that ample organizations exist for the conduct of such studies and that further groups were not needed. The motion that the recommendation be adopted by the Conference was defeated.

Professor Dunstan moved that the Conference chairman act to establish a Committee representing EEIB, ASEE, and AAPSE and that this Committee function to continue the discussion of the many questions raised at this Conference. The motion was seconded and passed unanimously.

APPENDIX B
CONFERENCE ATTENDANCE

Andrews, John F.	Clemson University
Angelotti, Robert	National Center for Urban & Industrial Health Chevy Chase, Maryland
Arnold, Earl H.	National Center for Urban & Industrial Health Chevy Chase, Maryland
Aulenbach, Donald B.	Rensselaer Polytechnic Inst., Chevy Chase, Maryland
Austin, John H.	University of Illinois
Banerji, Shankha K.	University of Delaware
Baumann, E. R.	Iowa State University
Berger, B. B.	University of Massachusetts
Bevis, Herbert A.	University of Florida
Bloodgood, Don E.	Purdue University
Borchardt, Jack A.	University of Michigan
Boyle, William	University of Wisconsin
Brandt, Allen D.	Bethlehem Steel Corporation
Bryan, Edward H.	Duke University
Burgess, Fred J.	Oregon State University
Busch, A. E.	Rice University
Carlson, Dale A.	University of Washington, Seattle
Cember, Herman	Northwestern University
Christman, Russel F.	University of Washington, Seattle
Dahl, A. H.	Public Health Service, Wash., D.C.
Dick, Richard	University of Illinois
Dirasian, Henry A.	Wayne State University
Dunstan, Gilbert H.	Washington State University
Dworsky, Leonard	Cornell University
Echelberger, Wayne F.	University of Notre Dame
Engelbrecht, R. S.	University of Illinois
Engler, Hershel	DHEW, PHS, Bu. DTEC, Wash., D.C.
Erickson, Frederick K.	DHEW, PHS, DAHM
Etzel, James E.	Purdue University
Ewing, Ben	University of Illinois
Feng, Tsuan Hua	University of Massachusetts
Fishbein, Gershon	Environmental Health Letter
Fraust, Charles	Northwestern University
Gannon, John J.	University of Michigan
Gates, Charles D.	Cornell University
Gates, Wm. E.	Georgia Tech. Inst.
Gaudy, Anthony F.	Oklahoma State University
Gemmell, Robert	Northwestern University
Geyer, John C.	Johns Hopkins University
Gloyna, Ernest	University of Texas
Goldschmidt, Adam	Statens Naturvardsverk, Fack, Solna 1, Sweden
Gotaas, H. B.	Northwestern University
Graber, Ralph C.	Bureau of Health Manpower, USPHS, Arlington, Va.
Gurnham, C. Fred	Ill. Inst. of Technology
Gustafsson, Bengt	Royal Inst. of Technology, Stockholm 70, Sweden
Hanes, N. Bruce	Tufts University
Hann, Roy W.	Texas A. & M. University
Hanson, Harry G.	Pan American Health Organization, Wash., D.C.
Harrington, J. J.	Harvard University
Hazen, Richard	Hazen & Sawyer
Heaney, James	Battelle Northwest, Richland, Wash.
Heinke, A. W.	University of Toronto
Heiple, Loren R.	University of Arkansas
Hermann, Edward R.	Northwestern University
Isaacs, W. B.	New Mexico State University
Jenkins, Charles R.	University of West Virginia
Jeris, John	Manhattan College
Johnson, J. Donald	University of North Carolina
Johnson, Walter K.	University of Minnesota
Jones, P. H.	University of Toronto
Kaufman, Warren J.	University of California, Berkeley
Kiker, John E., Jr.	University of Florida
King, Paul H.	Virginia Polytechnic Inst.
Kirsch, E. J.	Purdue University
Kramer, Harry P.	Public Health Service, Wash., D.C.
Krone, Ray B.	University of California, Davis
Lanoix, Joseph N.	World Health Organization, Geneva
Larson, T. E.	Illinois State Water Survey
Linsky, Benjamin	West Virginia University
Littleford, Robert A.	National Center for Urban & Industrial Health, PHS

Loehr, Raymond	Cornell University
Logan, John A.	Rose Polytechnic Inst.
Loucks, Daniel P.	Cornell University
Ludwig, Harvey F.	Engineering-Science, Inc.
Lynn, Walter R.	Cornell University
Malhotra, S. K.	Marquette University
Mancini, John L.	Hydroscience Inc.
Martinez, Joseph D.	Louisiana State University
McCabe, Joseph	Manhattan College
McCarty, Perry L.	Stanford University
McGauhey, P. H.	University of California, Berkeley
McKinney, Ross	University of Kansas
McLellon, W. M.	Clemson University
Mees, Quentin M.	University of Arizona
Meserve, Robert L.	Northeastern University
Meyer, Alvin F., Jr.	HQ. USAF-AF MSP-1, Wash., D.C.
Miller, Alvin	Northwestern University
Molof, Alan H.	New York University
Mood, Erik	Yale University
Morand, James M.	University of Cincinnati
Morris, J. Carrell	Harvard University
Murphy, R. S.	World Health Organization, Wash., D.C.
Myrick, H. Nugent	University of Houston
Nevins, Frederick	
O'Brien, Walter J.	University of Kansas
O'Connor, D. J.	Manhattan College
O'Connor, John	University of Illinois
Oglesby, R. T.	University of Washington, Seattle
Okun, D. A.	University of North Carolina
Oswald, Wm. J.	University of California, Berkeley
Parker, Frank	Vanderbilt University
Paulson, Wayne L.	University of Iowa
Pearson, E. A.	University of California, Berkeley
Pfeffer, John T.	University of Illinois
Pipes, W. O.	Northwestern University
Phillips, Robert	Northwestern University
Pohland, Fred G.	Georgia Tech. Inst.
Polkowski, L. B.	
Pretorius, William A.	National Water Resources Institute, South Africa
Preul, Herbert C.	University of Cincinnati
Purdom, P. W.	Drexel Institute of Tech.
Putnam, Hugh D.	University of Florida
Quon, J. E.	Northwestern University
Reid, George	University of Oklahoma
Rich, L. G.	Clemson University
Rogers, Jerry R.	Southern Methodist University
Rohlich, G.	University of Wisconsin
Rossano, August T., Jr.	University of Washington, Seattle
Rumer, Ralph R.	State University of New York, Buffalo
Russell, Richard	Northwestern University
Ryckman, D. W.	Washington University
Sanks, Robert L.	Montana State University
Scarpino, Pasquale V.	University of Cincinnati
Scherfig, Jan	University of California, Irvine
Schooley, Ralph	Schooley Engr. Co., Indianapolis
Schroeder, Edw. D.	University of California, Davis
Schroepfer, George J.	University of Minnesota
Shapiro, Maurice	University of Pittsburgh
Shuval, Hillel	U. of Mich. S. PH.
Skrinde, Rolf T.	University of Massachusetts
Snow, Donald L.	National Center for Radiol. Hea.
Sproul, Otis J.	University of Maine
Stephenson, Marvin E.	Michigan State University
Stevenson, Albert H.	U.S. Public Health Service
Straub, Conrad P.	University of Minnesota
Sylvester, Robert O.	University of Washington, Seattle
Tenney, Mark W.	University of Notre Dame
Thomann, Robert V.	Hydroscience, Inc.
Thomas, Harold	Harvard University
Thorson, Ted	Northwestern University
Unz, Richard	Pennsylvania State University
Walters, Charles	National Center for Air Pollution Control
Ward, John C.	Colorado State University
Washington, Donald R.	Rensselaer Polytechnic Inst.
Weber, Walter, J., Jr.	University of Michigan
Weers, Walter A.	Clemson University
Weidenkopf, Stanley	University of North Carolina
Weinbrenner, Loren L.	Northwestern University
Westfield, James D.	Georgia Tech. Inst.
Wilson, Thomas E.	Rutgers University
Wolszon, John D.	Purdue University
Woodward, Richard L.	Camp, Dresser, & McKee
Zanoni, A. E.	Marquette University
Yarne, Jeffrey	Northwestern University