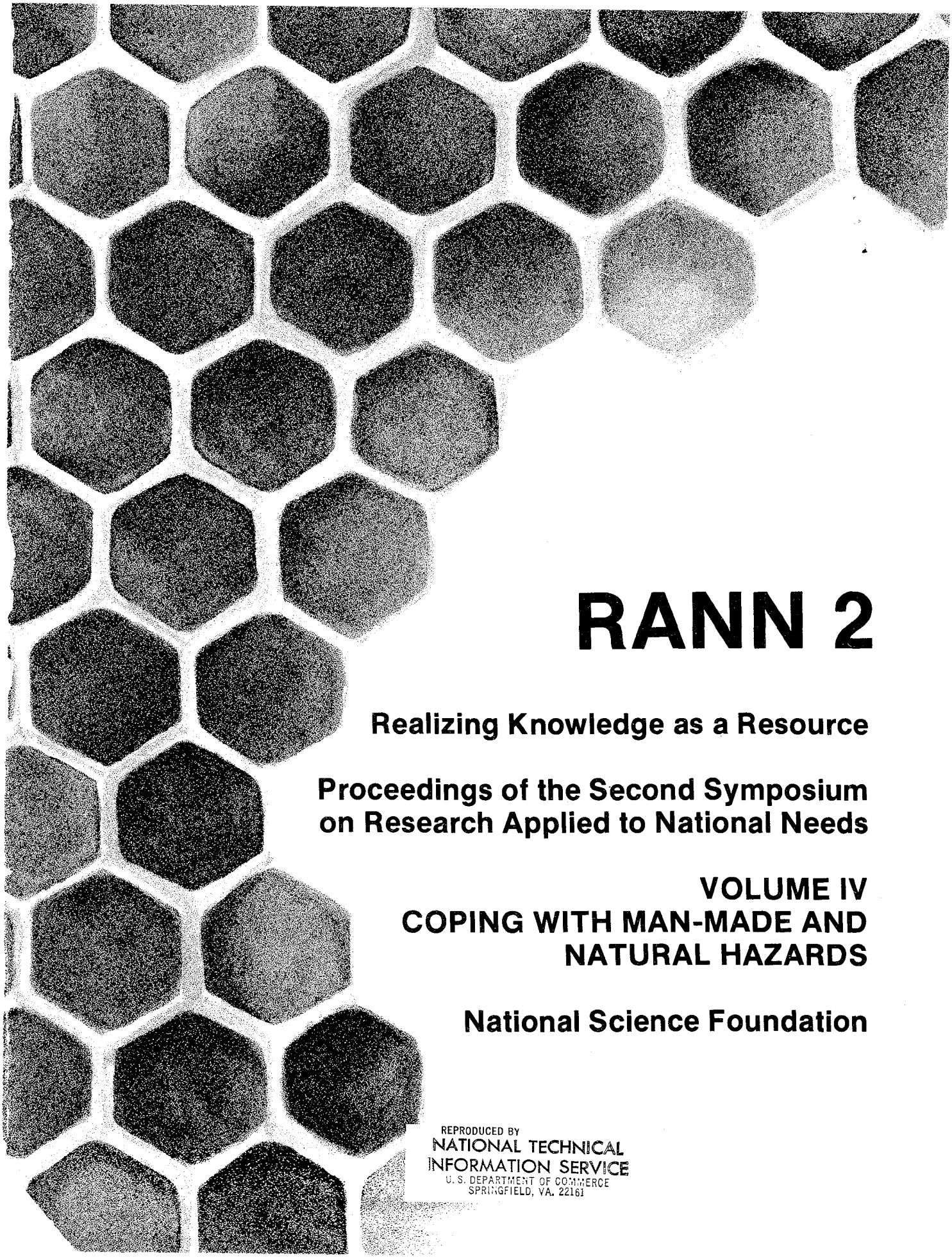

RANN 2

Realizing Knowledge as a Resource

Proceedings of the Second Symposium on Research Applied to National Needs

VOLUME IV
COPING WITH MAN-MADE AND NATURAL HAZARDS

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Summary of Volume IV

The research presented in this volume represents man's efforts to cope with natural and constructed environments. Natural and man-made hazards often pose serious environmental threats. Some byproducts of man and his works are presently or potentially destructive to the environment, but might be manageable through selected technologies and ultimately promote the well-being of both man and his environment. In some areas, the environment has not yet been altered by man to meet his needs, and when such alterations are under consideration, research can help man design his interactions with the constructed environment with minimal losses to the natural environment.

RANN has promoted research on the economic, ecological, social, political, and technological aspects of the problems which man creates and/or encounters in his own environment. In each of these areas, RANN research has sought methods and technologies that will aid in the understanding and management of potential and actual hazards to man. RANN-supported research presented by panelists and roundtable participants includes studies on the following:

- Reduction of damage to man and his works from earthquakes.
- Socioeconomic, political, and physical losses that are consequences of all natural hazards, including, but not limited to, earthquakes.
- Use of municipal waste as a resource and the overall problems of municipal waste management with special attention to selected modes of treatment.
- Management of various environmental pollutants in the atmosphere, land, and water sources.
- Significance and consequences of the interdisciplinary design process as it affects environmental relationships
- Information and methods in regional environmental decisionmaking.
- Effects of physical alterations by man and nature on large water sources used by man.
- The effects of federal policies on land use and development.
- Two approaches to a risk assessment and social evaluation of environmental hazards of human origin.

1. Introduction

The RANN 2 symposium afforded a broad perspective on the diverse activities and concerns of the Research Applications Directorate of the National Science Foundation. To represent this diversity, the more than 160 papers and presentations given during the symposium were organized under 26 theme headings, including such topics as "Food Production and Delivery," "Coping with Learning Disabilities," and "Private Sector Productivity." The format of presentation also varied, with some topics being discussed in large panel sessions of over 200 persons and others being discussed in roundtable sessions of about 20 persons.

The Proceedings of the Second Symposium on Research Applied to National Needs have been organized in six volumes. Volume I presents the plenary session and introductory materials, an overview of the symposium, and an appendix containing lists of speakers, special guests, attendess, films, and exhibits. A full agenda for the symposium, also included in Volume I, indicates the volumes in which each speaker's paper appears. The alphabetical list of speakers in the Appendix to Volume I is also indexed for each speaker. To bring together related topics, the materials on the 26 themes have been assembled in Volumes II through VI, each of which focuses on an area of national need (see list below). When a paper was written by more than one author, the RANN 2 presenter is indicated by an asterisk. Each volume contains an author index.

Thus, the proceedings can be approached from any one of three directions: subject matter (by volume), author or speaker (by the author indexes), or chronology of symposium events (by the agenda). A complete list of the materials included in each volume follows.

Volume 1: General Information and Plenary Sessions

- Foreword
- Introduction
- RANN2: An Overview
- RANN 2 Agenda
- Plenary Addresses
- Toward the 1980s: Emerging National Needs
- Appendices

Volume II: Using Natural Resources

- Food Production and Delivery: Interactions with Energy and the Environment
- Increasing Crop Productivity: Applications of Photosynthetic Conversion
- Nonconventional Sources of Protein
- International Resources Interdependence
- Biomass Utilization

Volume III: Improving Productivity

- Productivity Improvement in the Private Sector
- The Private Sector: Problem Solution Through Industry-University Cooperative Research
- Private Sector Productivity
- Productivity in Administrative Services

Pages 1 and 2 are blank.

Volume IV: Coping with Man-Made and Natural Hazards

- Reducing Damage from Earthquakes
- Societal Response to Natural Hazards
- Municipal Waste as a Resource
- Environmental Design
- Regional Environmental Decision-making: Information and Methods
- Regional Environmental Management
- Environmental Risk Assessment and Evaluation

Volume V: Improving Government Responsiveness to Public Needs

- The Public Sector: Problem Identification and Solution at the Local Level
- Priority Problems of State and Local Governments
- Local Government Service Delivery
- Increasing Productivity Through Telecommunications
- Society and Its Interactions with Technology

Volume VI: Regulation

- Regulation of Financial Institutions
- Inflation and Public Policy
- Regulation and Its Impact on Food
- Regulation and the Economy

2

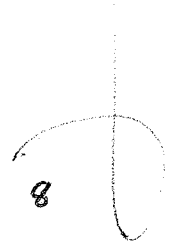
REDUCING DAMAGE FROM EARTHQUAKES

2. Reducing Damage from Earthquakes

RANN seeks methods and techniques that can provide more effective protection against the effects of earthquakes: loss of life, injury, property damage, social dislocation, and economic and ecological disruption. Research supported by RANN in this area has been applied to design provisions for regulatory code adoption and revision, computer programs for analysis of structure and functions, building design criteria and procedures, strong-motion data for earthquake force determinations, criteria for zoning, and data for public policies to implement earthquake warnings and post-earthquake recovery.

Specifically, the California Institute of Technology has participated in a RANN-sponsored project which has provided information for use in limiting future earthquake destruction. Potential property damage, life loss, injury, and social disruption from earthquakes can be appreciably reduced by adopting construction and public policy alternatives that are economically sound and socially realistic (Housner). The magnitude of the earthquake problem and suggested area of future research are presented from a structural engineer's point of view (Johnston). The University of California Earthquake Engineering Research Center has compiled experimental data on the actual behavior of structural components subjected to earthquake-type loadings, and offers explanations of the earthquake simulator and its limitations and capabilities (Clough). The interaction of RANN research on earthquakes and transfer of acquired information to current use is also presented (Hanson).

Panel Papers



Earthquake Damage and Earthquake Protection

George W. Housner
C.F. Braun Professor of Engineering, California Institute of Technology

Disastrous earthquakes continue to occur throughout the world, for example, 600,000 deaths, China, 27 July 1976; 22,000 deaths, Guatemala, 4 February 1976; 50,000 deaths, Peru, 31 May 1974. These disasters reflect inadequate preparations for defense against earthquakes. The first line of defense is earthquake-resistant construction, and its adequacy is tested by the occurrence of earthquakes. The earthquake damage sustained by structures in the United States not only points out weaknesses but also can point out how earthquake engineering can be improved; that is, the earthquake can be viewed as a full-scale experiment which, with appropriate preparations, can provide valuable information that can enhance public welfare and safety. One central question to be answered is: What level of investment is justified to provide protection against damage and loss of life in the event of extremely intense ground shaking produced by a great earthquake whose probability of occurrence is relatively small?

In designing a structure to resist earthquakes, it is very important to be able to evaluate the dynamic deformations and the stresses and strains that would be produced were ground shaking to occur. A knowledge of the physical properties of materials under dynamic loadings is needed, and methods for determining the optimum configuration of a structure and the proper sizes and shapes of structural members must be available. The ground beneath the structure must be considered an integral part of the structural system; consequently, questions such as the following arise: How will the ground respond to the seismic waves? Will it become unstable? Will it lose its strength? How will earth structures such as dams and embankments behave during an earthquake, and how should they be designed? The problems of analysis and design are made especially difficult because most structures will be designed to sustain damage in the event of strong ground shaking, in which case the stresses and strains will exceed the range normally permitted in engineering design.

The probability that a city will be within the area of strongest ground shaking of the maximum credible earthquake to occur in that region is small, and the cost of constructing to withstand that ground motion without damage would be relatively high. Economically, there is an optimal design depending on the probability of earthquakes of various intensities, the cost of providing earthquake resistance, and the cost of repairing earthquake damage. A suitable objective for ordinary structures is that there be no damage in the event of moderate ground shaking for which there is an appreciable probability of occurrence during the life of the structure and that, in the event of the less probable very strong ground shaking, the damage sustained should not be so severe as to be a hazard to life or limb. There are, of course, exceptions to this. The failure of some installations such as large dams and nuclear power plants is potentially so catastrophic that the structures must be designed to withstand the strongest likely ground shaking without significant damage. The establishment of an acceptable and efficient design solution requires a greater knowledge of earthquakes and their effects on structures than we now have, and the development of more powerful techniques of analysis and design than are currently in use.

The concentration of people, structures, and facilities makes cities especially prone to earthquake hazards. In

addition, since the per capita investment in structures and facilities is greater in cities than in rural areas, the growth of cities brings an increased likelihood of economic disaster as well as social disaster from earthquakes. The rate of investment in construction in the United States is approximately $150 billion per year, and in the seismic regions it is approximately $50 billion per year, most of which goes to the cities. The protection of this investment, as well as the safety of the inhabitants in the cities, will depend on developing improved methods of planning and building to resist earthquakes.

In coping with the earthquake problem, certain decisions must be made in response to the following questions: What constitutes excessive cost of earthquake protection? What constitutes adequate safety measures? What constitutes acceptable damage (how frequent)? What is the value of a human life? What constitutes unacceptable disruption of a city? What constitutes unacceptable social shock? A simplistic view would be that there should be no damage, no loss of life, and no disruption from earthquakes. Although it would be technically possible to accomplish this, the cost of providing such complete protection would be exorbitant. Although complete protection against moderate earthquakes can be provided at acceptable cost, it could not be provided for earthquakes which occur very infrequently. Although the probability that a city will experience intense ground shaking of long duration from a great earthquake is relatively small, it is certain that it will happen in the future as it did in the past to San Francisco (1906) and Tokyo (1923). The cost of providing complete protection is great, but the disaster that could occur if protection is not provided is also great. It is clear that the cost of providing complete protection against damage in the event of the maximum credible earthquake would be excessive, for a society can invest only so much in construction and, therefore, the cost of complete protection would require a reduction in the number of structures and facilities provided, and it appears unlikely that this would be acceptable to society.

A key question that must be answered in earthquake engineering is, How should structures be designed so that they receive no damage from moderately strong earthquakes that might occur relatively frequently and so that they will sustain only an acceptable degree of damage, without danger of collapse, in the event of the unlikely occurrence of extremley strong ground shaking? What constitutes acceptable damage is not yet clear, for it depends on how often such an event might occur as well as upon the severity of the event itself. It is generally agreed that some damage must be accepted, but that there should be little or no hazard to life or limb. When an earthquake occurs, all structures, facilities, and equipment in that region are subjected to the ground shaking and, therefore, protection requires earthquakeresistant design of a wide variety of the works of man. It is not sufficient that highrise buildings be made earthquake-resistant, but other buildings, dwellings, public utilities, industrial facilities, nuclear powerplants, liquid natural gas tanks, etc. must also have the necessary earthquake resistance. For each of these, it is necessary to understand the vibratory behavior they are subjected to during an earthquake shaking, and it is necessary to know how they should be designed to withstand moderate shaking with no damage and withstand very severe shaking with moderate damage that will not endanger the integrity of the structure or facility.

The observed damage sustained by structures and facilities during actual earthquakes is an important source of information. From the research point of view, an earthquake is a full-scale experiment. It is the only time that actual high-rise buildings, dams, nuclear reactors, bridges, etc. are subjected to strong shaking. Measurements made of the vibrations of these structures enable research workers to understand precisely how these structures behaved and what stresses and strains were developed. Special accelerographs have been installed in selected structures to record the shaking of the ground and the shaking of the structure itself. As part of a RANN-sponsored program at the California Institute of Technology, recording instruments were installed in the main engineering building at the Jet Propulsion Laboratory. This structure was 12 miles from the nearest portion of the causative fault of the February 9, 1971, San Fernando, California, earthquake (Magnitude 6.5). The motions recorded on the roof and in the basement of this nine-story, steel-frame building are shown in Figure 1. In this case the maximum stresses induced in the structural frame were just at the yield point. Had the ground shaking been appreciably more intense the steel members would have been subjected to plastic deformation and possibly failure. When plastic deformation or damage occurs, the physical properties of the structure change and the vibratory response to ground shaking is different. This nonlinear behavior and the energy dissipation make it more difficult to analyze the vibratory response and to determine how close to collapse the structure would be if subjected to strong ground shaking.

If the earthquake ground shaking is intense enough to cause damage, this calls attention to structural weaknesses and indicates where research is needed to make improvements in design. Structures that were not designed to resist earthquakes are especially susceptible to damage from strong ground shaking and, in some countries, weak buildings have led to large loss of life and severe economic losses. Figures 2 through 7 show earthquake damage sustained by various structures. In some instances the structures were very poorly designed and consequently received severe damage, even though the ground shaking was not exceptionally intense; in other cases modern structures that had been designed to resist earthquakes were damaged by unexpectedly intense ground shaking. At present, there is considerable concern over the fact that cities in the United States have numerous old, weak buildings that have the potential for earthquake disaster. A RANN-sponsored project at the University of California is studying this problem to determine how such structures can be given earthquake resistance at an acceptable cost.

The solution of the earthquake protection problem is particularly difficult because of the necessity to consider the probabilities of occurrence. The fact that a disaster

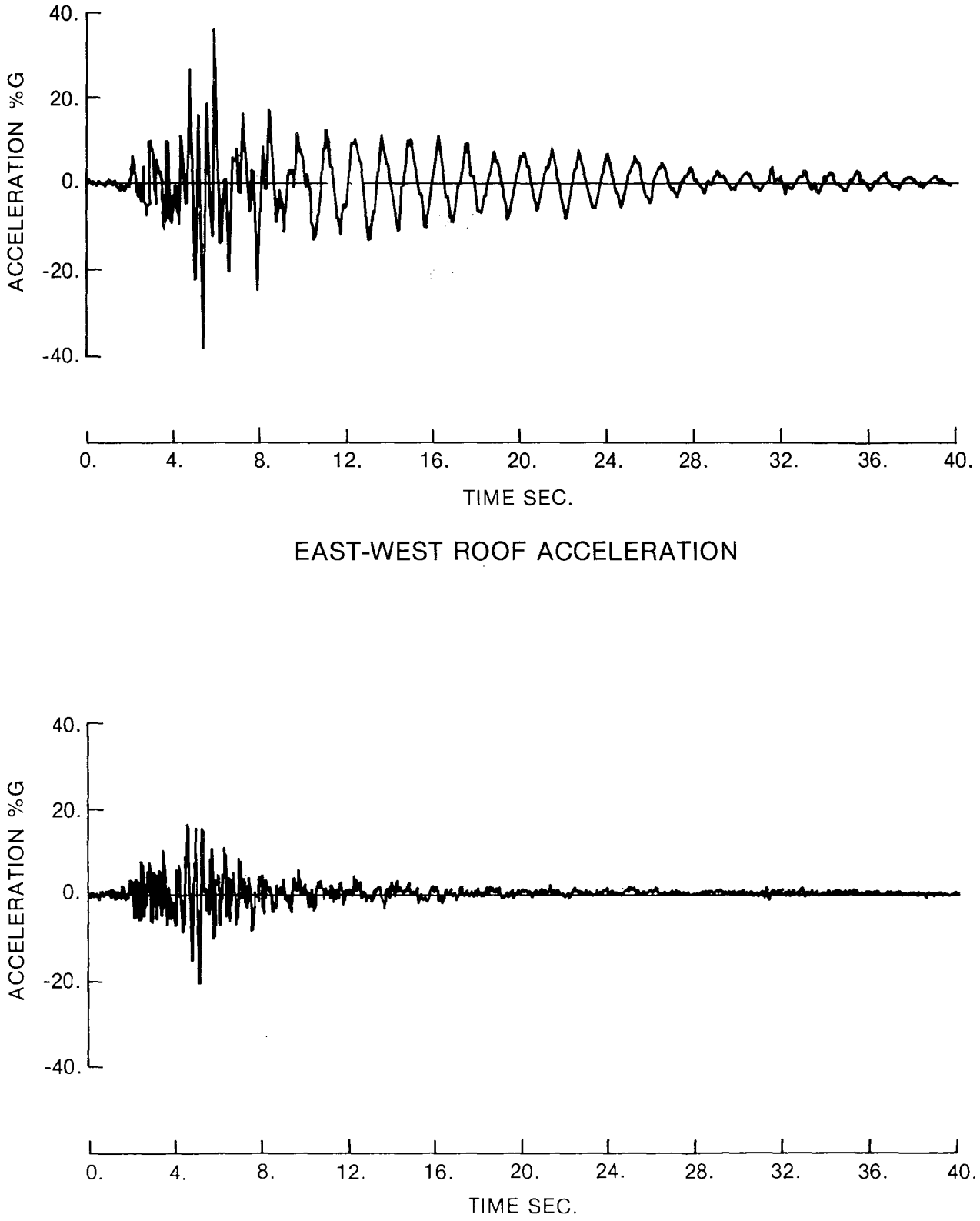


FIGURE 1—Recorded roof and basement accelerations in the engineering building at the Jet Propulsion Laboratory in Pasadena. This nine-story, steel-frame structure was approximately 12 miles from the causative fault of the Magnitude 6.5 San Fernando, California, earthquake of February 9, 1971.

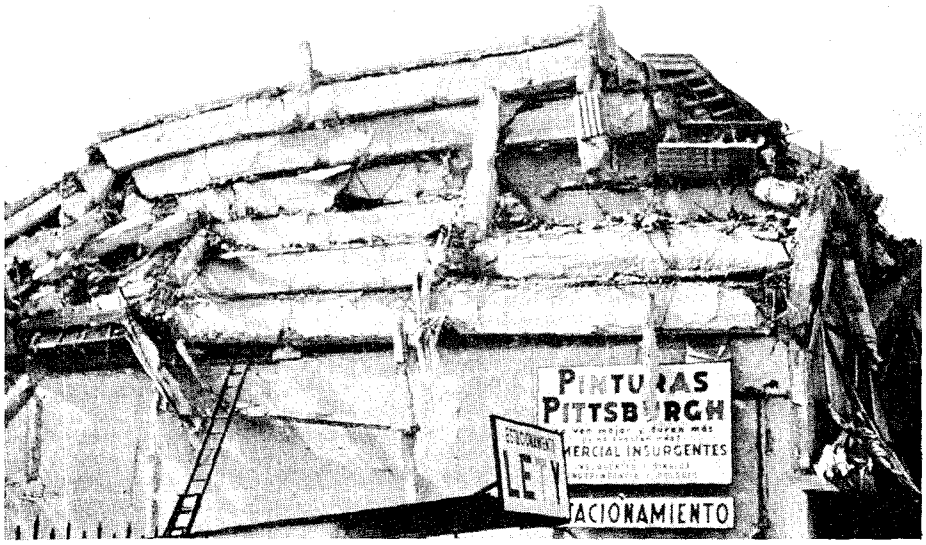


FIGURE 2—This eight-story apartment building in Mexico City collapsed during the earthquake of 1957; the upper floors pancaked onto the second floor.

FIGURE 3—This railway tunnel in southern California passed through the fault zone of the 1952 Tehachapi, California, earthquake of July 21, 1952. Rock movements produced by faulting shattered the tunnel.

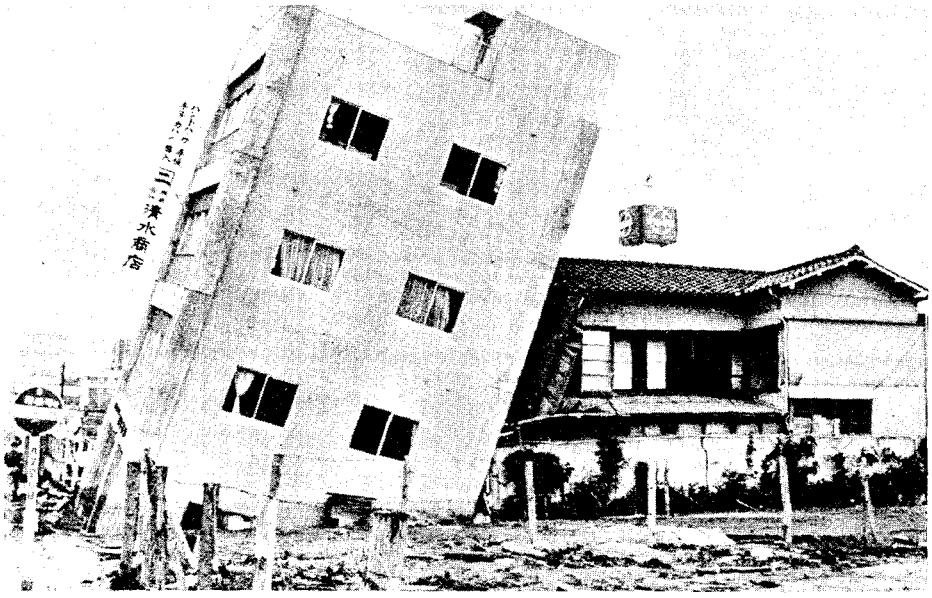


FIGURE 4—The 1964 earthquake (Magnitude 7) that shook the city of Niigata, Japan, caused widespread liquefaction of the sandy soil with high water table. ManY structures settled and tilted out of plumb.

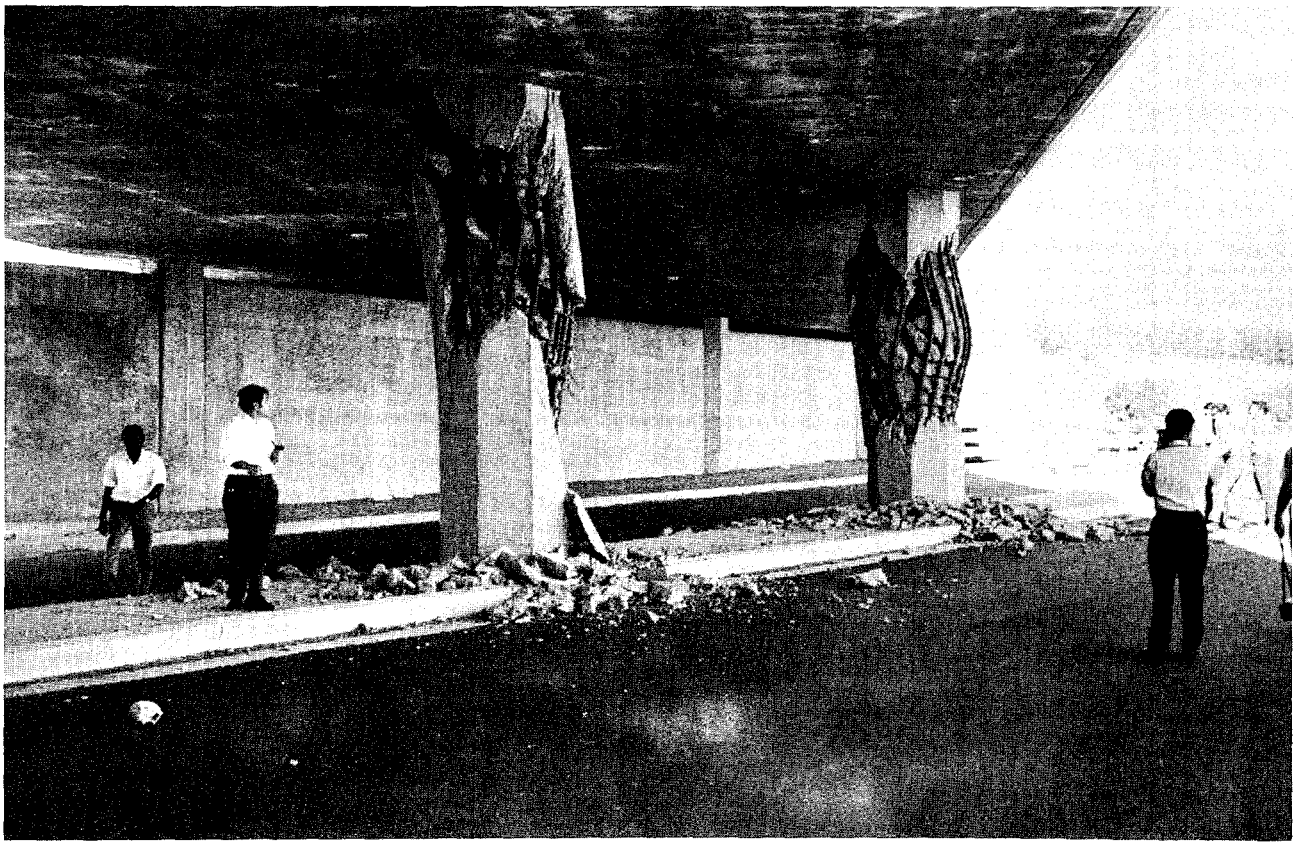


FIGURE 5—A number of freeway bridges were severely damaged by the February 9, 1971, San Fernando, California, earthquake.

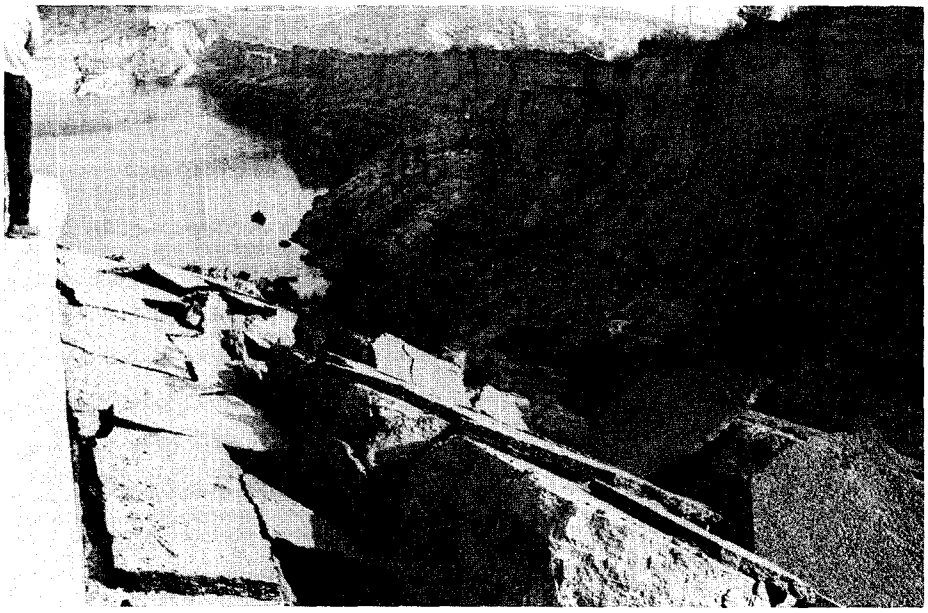


FIGURE 6—The lower San Fernando Dam (built in 1915) was severely damaged by the February 9, 1971, San Fernando, California, earthquake. Eighty thousand persons were evacuated from their homes in the region below the dam until the water behind the dam had been drawn down to a safe level.

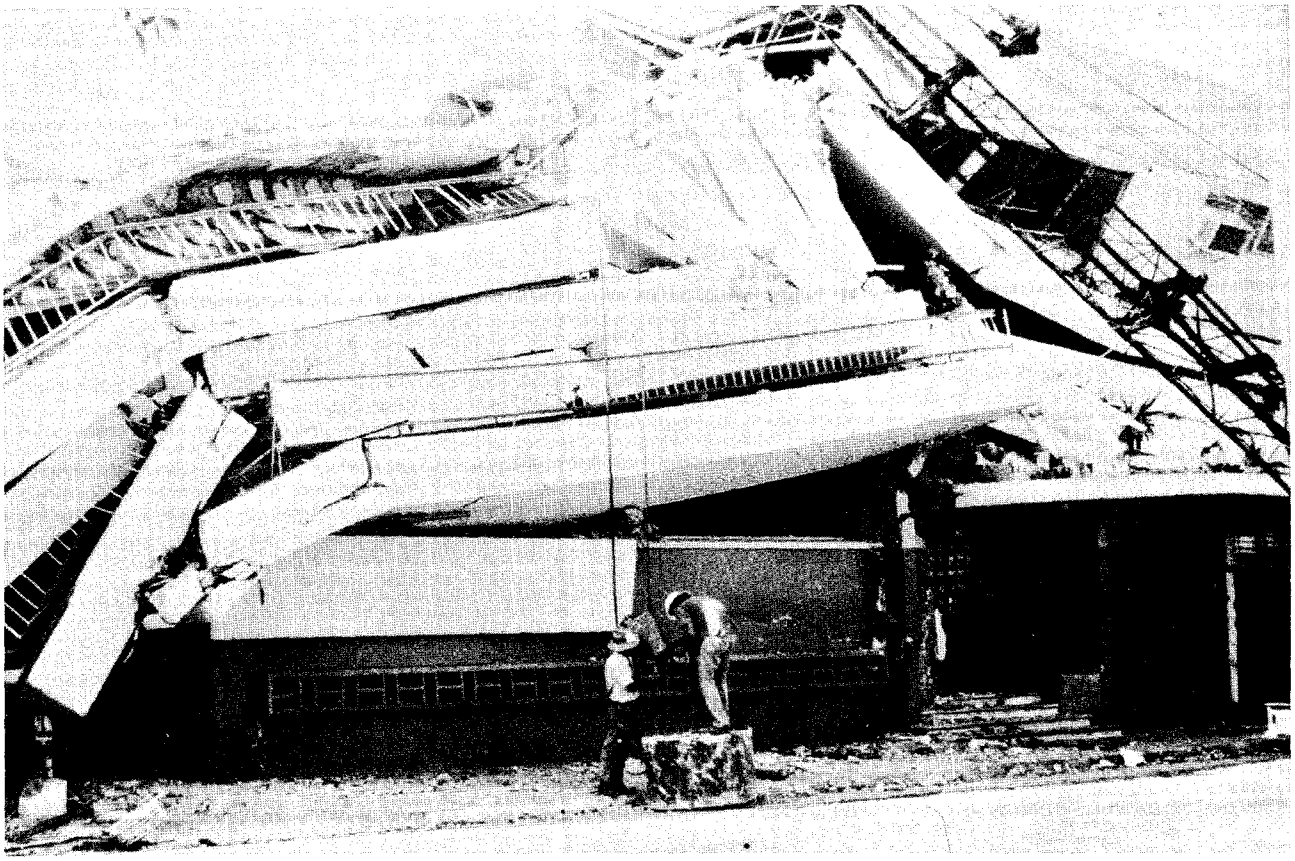


FIGURE 7—Building that collapsed during the Managua, Nicaragua, earthquake of December 23, 1972.

can be expected to occur relatively infrequently makes it difficult to reach a decision with confidence. The uncertainty involves not only the occurrence of infrequent great earthquakes, but depends in a probability sense on other factors as well. For example, a scenario for a great earthquake disaster in a metropolitan area in southern California might read as follows:

(1) A large earthquake occurs, producing very strong ground shaking.

(2) The earthquake occurs during the middle of the day when many persons are on the streets and sidewalks, and many are in commercial and industrial buildings.

(3) Many old, weak buildings collapse wholly or in part.

(4) Some newer buildings are severely damaged.

(5) Many fires start.

(6) Some parts of the city are without water for fighting fires.

(7) There is low atmospheric humidity and high temperature.

(8) A strong wind is blowing.

(9) Several freeway bridges collapse, blocking traffic.

(10) Electric power and gas are unavailable.

(11) Communications are out.

(12) Collapse of law and order.

If all, or most, of the foregoing occurred at the same time, there would be a great disaster. Actually, there is only a certain probability that each of the foregoing 12 conditions will be in effect at that time, and the probability that all of them will be in effect at the same time is very small. However, the fact that an extreme disaster has only a small likelihood of occurring does not mean that it can be ruled out of consideration. In past U.S. earthquakes the conditions for a great disaster were not in effect, and through this good fortune the number of deaths was much smaller than might otherwise have been the case. The probability of each component contributing simultaneously to a disaster should be reduced to a satisfactorily low level at an acceptable cost. Unfortunately, at present not enough is known about these factors to make decisions with confidence. Coping with future earthquakes will depend on the following items: increasing knowledge about earthquakes and their effects, improving resistance of structures to earthquakes, and organizing efficiently for disaster mitigation. These will each require appropriate research.

A User's View of Earthquake Research

Roy G. Johnston
Vice President, Brandow and Johnston Associates

Structural engineers who design structures in regions exposed to major earthquakes are frequent users of information, data, and techniques that have flowed from scientific research and studies in earthquake engineering. This paper focuses attention on the magnitude of the earthquake problem and the necessity to protect lives and reduce the damage to property worth billions of dollars. It reviews some of the areas in which knowledge has advanced in the last 15 years and suggests areas for future study and research.

It is a privilege for me to be a part of this panel of distinguished engineers and to share with this audience my views as a user of the many programs sponsored by the National Science Foundation in earthquake engineering research. I am a consulting structural engineer, practicing in earthquake country. Our office, with less than 40 engineers and draftsmen, is responsible for the structural design of several thousand building structures, many of which date back to the late thirties.

Albeit these structures have been designed to the seismic code and engineering standards applicable at the time and should resist earthquake forces as well as other structures constructed in the same period, such rationalization is small comfort when we realize today what can happen in a major destructive earthquake and what can be done to protect property and save human lives. The lessons learned in the 1971 San Fernando earthquake are all too recent for any responsible engineer to ignore. The discovery of an ominous ten-inch bulge in the earth's crust in Southern California has called special attention to the possible devastation caused by slippage of the San Andreas fault in the vicinity of Los Angeles. Our senior senator from California, the Honorable Alan T. Cranston, speaking in support of the Earthquake Hazards Reduction Act, said: "Experts estimate that a major quake in that area could kill twelve thousand people, seriously injure three times that amount, and cause twenty-five billion dollars' property damage."

A similar situation exists in the San Francisco area. A recent study by the federal government showed that earthquake hazardous buildings in the metropolitan San Francisco Bay area could cause as many as 10,000 deaths in the event of the maximum credible earthquake occurring on the San Andreas fault. In other words, this possible event, although we trust very infrequent, would be the reoccurrence of an earthquake as strong as the San Francisco shock of 1906. Although the study focused attention on the life hazard, it is not difficult to foresee damage to property in the billions of dollars.

This damage may be to our homes, our schools, and our churches, It can occur in all types of structures—skyscrapers, power plants, bridges, pipelines, dams, factories, refineries, and drilling platforms. The list is endless. Each year, over $150 billion are invested in new construction, of which $30 billion are invested in highly seismic regions. It is this cumulative investment and the

potential loss of life which must be protected from the destructive effects of major earthquakes.

The recent earthquakes in Guatemala, Italy, the Soviet Union, and China emphasize the urgent need to support scientific studies of ways to predict and possibly control earthquakes, to plan for better land use, and to improve the earthquake-resistant design of all types of structures. Our objective must be to achieve adequate safety for our citizenry and our cities at a reasonable cost.

If we compare the state of knowledge as it existed, let us say, in March 1933—the year of the Long Beach earthquake—with the design process as it is known today, there is a marked difference. At that time, the understanding and representation of the effect of an earthquake were summarily stated in a single paragraph.

I quote from Mr. John Freeman in his book *Earthquake Damage and Earthquake Insurance:*

> "All buildings in a region liable to earthquake violence equivalent to that of the known seismic regions of Italy, Japan and of the United States, should be designed to resist a horizontal earthquake force applied at each floor level equal to one-tenth of the weight of all of the structure above that level, plus the weight of the actual contents resting upon all floors including the roof."

In other words, the seismic factor commonly adopted was a horizontal earthquake acceleration equal to one-tenth of the acceleration due to gravity.

In the intervening years, considerable progress has taken place in earthquake engineering which has been reflected in the seismic codes and ordinances. The first seismic ordinance in the City of Los Angeles, enacted in 1933, required a coefficient of eight percent of the dead load plus half live load. Ten years later, in 1943, this coefficient was changed, making the magnitude of the coefficient a function of the numbers of stories. For a one-story building, the coefficient was 13.3 percent; for a 13-story building, a limiting height, the coefficient was 3.4 percent. This revision recognized, although indirectly, the influence of flexibility of the structure on the earthquake design factors. In 1959, the story height limitation was removed. During this same period, a general revision of the code took place,primarily through the influence of the Structural Engineers Association of California. Included in the regulations were modifying factors based upon the estimated period of the structure and the type of framing system. In 1966, detailed requirements for ductile moment resisting space frames were introduced, and in 1974, factors pertaining to the importance of the use of the structure and the influence of the soil types were included.

During this entire period, there was an increasing awareness of the necessity of relating the design forces to a more realistic appraisal of the actual forces measured by earthquake recording instruments and of approaching the analysis of the structure more on the basis of a "dynamic" analysis than as a "static" equivalent computation.

In 1974, the Applied Technology Council, funded by RANN, commenced the task of coordinating the present state of earthquake knowledge, formulating new recommendations of lateral force requirements, and writing a new earthquake code. This new endeavor will incorporate the latest technological development. At the present time, it is possible to know the nature of destructive ground shaking; to measure the magnitude of earthquakes, and with reasonable accuracy to predict the nature and magnitude of future earthquakes; to use the digital computer to simulate these earthquake ground motions; to analyze with the aid of computers the dynamic response of buildings to ground motion and the stresses and strains in building structures; and to compute building-ground interaction and stresses in soil. This process is not limited to building design because it is equally possible to compute earthquake response, stresses, and strains in long-span bridges, large earth or concrete dams, nuclear power plants, pipeline structures, etc. Almost all of this capability in earthquake engineering is a direct result of research in the last 15 years.

It is of special interest to me that if we were to itemize only those research projects in which the members of this panel were involved, and which were funded by RANN, the list would be long and imposing. This I will not attempt to do, but a few of these areas are the computerized simulated earthquakes; the concept of response spectra; earthquake response computer programs; stress distribution in building assemblies, such as panel zones in rigid joints; studies in ductility; and others. In fact, it was only a few weeks ago that we found very useful and helpful studies in "The Dynamic Behavior of Water Tanks," "Damping Capacity of a Steel Structure," "Cyclic Loading of Full Size Steel Connections," and the "Seismic Behavior of Staggered Truss Framing Systems."

In spite of the rapid progress in earthquake engineering, the current situation is still in many respects similar to that facing structural engineers in 1939, when Henry Dewell, a pioneer in earthquake engineering, wrote:

> "The structural engineer, in designing earthquake resistant structures, is faced with the dilemma of furnishing a safe design immediately based upon incomplete data derived from a study of earthquake effects which is yet in its infancy. Fortunately, the empirical rules of construction based on the observation of the effects of earthquakes, coupled with the sound judgment and intuition of the experienced designer and the excellent construction materials now available, make it possible for the structural engineer to provide for the adequate performance of his structures."

Those of us who are concerned with the development of seismic codes or standards of practice are all too aware of the complexity of the problems and difficulties in finding solutions. In the actual practice of designing earthquake-resistant structures, there exist many points of view, opinions, and ideas, almost as many as there are structural engineers. Why is this? Because in many respects, the data or the evidence relating to special problems is inconclusive. The research, the study, and the confirming test programs have not been extended into that particular field. For example, there have been many materials, structural members, and even assemblies tested for static loads but very few for cyclicloads. There is a vast reservoir of knowledge demonstrating the behavior of materials, members, and assemblies within the yield range, but beyond, into the plastic range, there is

a scarcity of information. We refer to these situations only to suggest that there are many more areas to investigate and study. Engineering research is far from complete.

Numerous specific recommendations for research in the fields of seismology, geology, and engineering have been carefully developed and explained. Possibly the most significant of these was the publication *Report of the Task Force on Earthquake Hazard Reduction—Program Priorities,* Executive Office of the President, Office of Science and Technology (1970).

Recently, the Earthquake Engineering Research Institue Committee on Research Needs outlined six topics that it felt merited further research and which offered prospects of a good cost-benefit ratio for money spent on applied research. These were:

- Development of standard procedures for setting site specific design conditions;
- Development of standard procedures for the evaluation, and repair of existing facilities;
- Development of procedures of definition of acceptable levels of risk for new and existing facilities;
- Development and implementation of procedures for defining, predicting, and documenting the strong motions arising from earthquakes;
- Development of standard procedures of interpretation of strong motion records for design purposes; and
- Defining the effects of earthquake prediction on engineering practices.

Interpreting these recommendations in specific terms, I might suggest that the urgent need is for better information on the occurrence of major or strong earthquakes and the nature of their ground shaking; for additional data on the dynamic behavior of soils and foundations; for studies in the dynamic properties of building materials, subassemblies, and resisting elements; for research in the failure mechanism of structures, in nonlinear behavior of materials, in factors of safety at ultimate failure; and certainly for a clarification of the optimum cost-benefit ratio for earthquake protection.

In conclusion, if earthquake hazard reduction is to be achieved, it can only be accomplished by a continuing awareness of the destructive nature of major earthquakes and a national will to learn and develop new knowledge, methods, and techniques for mitigating the consequences of earthquakes.

Earthquake Simulator Research on Seismic Damage

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To develop analytical procedures for predicting the response of structures to earthquakes, it is necessary to compile experimental data on the actual behavior of structural components subjected to earthquake-type loadings. One of the most useful experimental facilities for obtaining such test data is the Earthquake Simulator of the University of California Earthquake Engineering Research Center. In this paper, the principal features and capabilities of this NSF-funded facility are described, and several examples of test programs which have been conducted on the simulator are discussed. Limitations of the present facility are mentioned, and procedures for overcoming some of these are suggested.

A major earthquake such as the one that recently destroyed Tangshan, China, a city of a million inhabitants, is the most severe loading to which the majority of civil engineering structures might ever be subjected. The engineering profession is fully competent to design and construct almost any structure strong enough to survive such an event with little or no damage. However, severe earthquakes are extremely rare at any location, and most structures will serve their full life without ever feeling a strong quake. Therefore, it is not economically justifiable to make all structures earthquake-proof; it is better strategy for most structures to repair the damage which may occur in the event of a strong earthquake.

On the other hand, buildings must be made strong enough to avoid collapse and other life hazard during strong ground shaking, though severe damage may take place. Thus, to meet the dual requirements of life safety and construction economy, the earthquake engineer must design a structure that will withstand an acceptable amount of seismic damage. This is more complicated than merely making the building strong enough that no damage takes place, and clearly it requires reliable prediction of damage which will occur during ground motion.

Analysis of the damages which may occur in structures during severe ground motions is a problem in nonlinear structural analysis. Computer procedures, such as the finite element method, have been developed and refined to the point where they can perform nonlinear dynamic analyses of almost any type of structure. However, for such analyses to be valid, it is necessary to provide a mathematical model of the structure which accurately describes its nonlinear behavior mechanisms while damage takes place. Such models can be developed only by experimental study of the building materials and components.

The urgent need for experimental facilities to evaluate the nonlinear behavior of structures during earthquakes was recognized more than a decade ago. Computer procedures for calculating structural damages during earthquakes had been developed by that time, but the necessary data on the inelastic behavior of structural components subjected to large amplitude cyclic, earthquake loadings were not available. It was largely to initiate studies on this problem that the Earthquake Engineering Research Center (EERC) was formed at the University of California, Berkeley. With the financial support of the National Science Foundation, several dif-

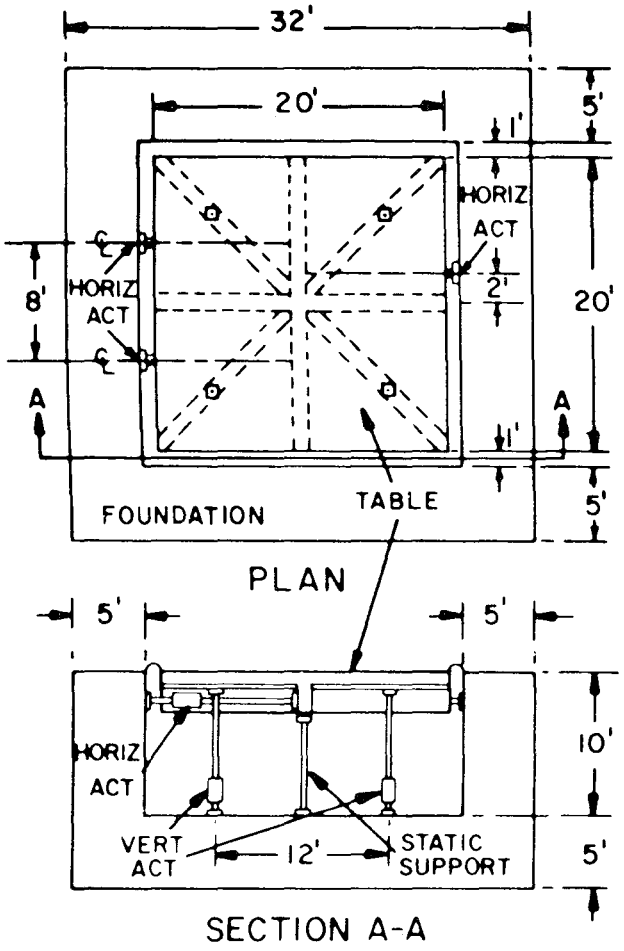


FIGURE 1—Layout of earthquake simulator.

ferent types of dynamic structural test facilities were designed and constructed—each capable of subjecting structural systems to simulated earthquake deformations. The most versatile of these, the EERC earthquake simulator or shaking table, is the subject of this paper.

THE EARTHQUAKE SIMULATOR FACILITY

The EERC earthquake simulator (Fig. 1) is the largest in the United States, and has the most sophisticated testing capability of any such facility in the world. The shaking table is a reinforced and post-tensioned concrete slab, 20 feet square by one foot thick. It is supported by hydraulic actuators in a concrete foundation block that weighs 1.5 million pounds; the actuators are arranged so as to drive the table in one horizontal and one vertical component. Another feature of the system is that the space between the edge of the table and the test pit is sealed by a rubberized fabric membrane. This permits the introduction of air pressure into the test pit to support the dead weight of the table and test structure; thus the vertical actuators need only supply the vertical accelerations.

The shaking table weighs about 100,000 pounds and can support a maximum test structure weight of 120,000 pounds. With full test load, the table can produce a peak acceleration horizontally of two-thirds gravity, and vertically of four-tenths gravity. The control system can

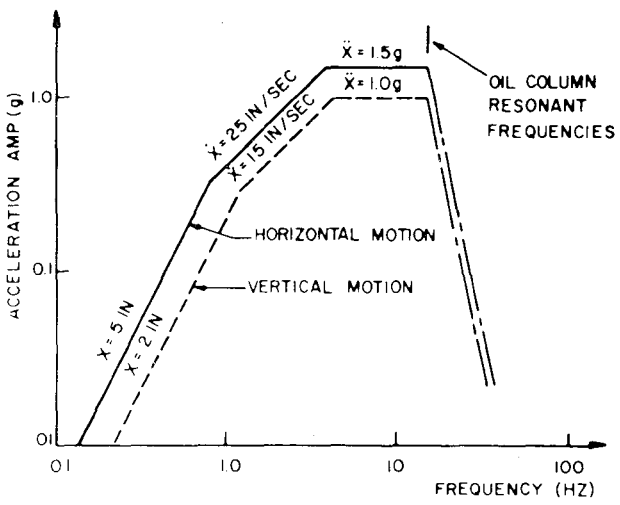


FIGURE 2—Dynamic performance limitations of simulator.

produce motions simultaneously in the two components; typically accelerograms recorded during actual earthquakes are used as the input signals. The operational limits of the shaking table without test structure are shown in Fig. 2; it is limited by displacement, velocity, and acceleration, respectively, in the low, medium, and high frequency ranges.

Associated with the shaking table is a minicomputer-based data acquisition system. This system has a capacity of 128 channels, and can sample the dynamic response information transmitted through each channel at a rate of up to 100 samples per second (although in normal usage the sampling rate is limited to 50 per second for increased reliability). The dynamic response information is recorded in digital form on a magnetic disc, and then is transferred to magnetic tape for permanent storage. The minicomputer performs preliminary data processing during the test, such as zero corrections and channel averaging. It also prints out a listing of the maximum and minimum readings in each channel, the time when it occurred, and time-history plots of selected channels.

BUILDING FRAME UPLIFT TEST

The function of the earthquake simulator is to subject attached test structures to motions similar to those that they would experience in a major earthquake, so that the actual earthquake behavior may be observed and studied in detail. Suggestions for tests to be performed on the simulator generally come directly from the engineering design profession as a result of problems which arise in practice. A good example of such an investigation is the current study of earthquake-induced uplift at the column footings of a building frame. A severe horizontal earthquake motion tends to cause a tall building to begin to overturn, and present building codes require that the footings be anchored into the foundation to prevent the uplift associated with this overturning tendency. However, no building will be overturned by an earthquake; the uplift tendency is only momentary, and the footing will immediately return to ground as the earthquake motion

reverses direction. So the value of the expensive foundation anchor requirement has been questioned; why not allow the footings to uplift?

To study this question, an existing three-story steel building frame model, shown in Fig. 3, was modified to permit the column footings to uplift. The special bearing details designed for the column bases, shown in Fig. 4, included a rubber pad to cushion the shock as the uplifted footing returned to its support. When subjected to a severe horizontal earthquake motion, this test structure rocked on its base, with uplifting displacements of over three inches occurring at the footings, as shown in Fig. 5.

The purpose of such an earthquake simulator test is not merely to observe the earthquake performance of a specific structure, but more importantly to validate and improve analytical methods for predicting such performance. A building which undergoes uplift during an earthquake is a highly nonlinear system, but it is apparent in Fig. 5 that the analytical result compares well with the experimental observation. Thus, the analytical procedure is demonstrated to be reliable in this instance, and it should be equally capable of predicting the uplift performance of real buildings subjected to real earthquakes.

Results of this test demonstrated that the building frame can be permitted to uplift during an earthquake, and that the stresses in the structure are reduced if uplift is permitted. This performance indicates that the problem should be studied further, and an additional test program is now being planned using a test model which will more accurately represent a typical building frame. If that study is as successful as this preliminary test, we expect to recommend modifications of the building code to eliminate the need for uplift anchors in typical building frames.

CYLINDRICAL LIQUID STORAGE TANKS

The second test program also was suggested directly by the design profession. The subject of investigation is the earthquake behavior of cylindrical liquid storage tanks. Many such tanks have been damaged in earthquakes. Fig. 6 shows the typical "elephant foot" buckling damage at the base of a tank.

The seismic design of cylindrical liquid storage tanks is based on an approximate analysis of the hydrodynamic pressures developed in a *rigid* tank during earthquake motions. However, these thin steel shells obviously are not rigid and the complex, dynamic fluid-structure interaction mechanism is not well understood at present. A group of petroleum-producing companies, tank manufacturers, and engineering design firms proposed a three-year shaking table study of the problem. Four tank models are included in the research program, but results of only one of these will be mentioned here. This is a 6-foot high by 12-foot diameter cylinder (Fig. 7), fabricated from sheet aluminum to simulate a steel tank at three times larger scale. Basic testing parameters included the type and intensity of earthquake excitation, the top boundary condition (open or with two different types of roofs), and the depth of water in the tank, but the most important test parameter was the base support condition—either fully clamped or free to uplift.

Response measurements included the shaking table accelerations and displacements, radial and tangential displacements of the tank relative to the table, surface

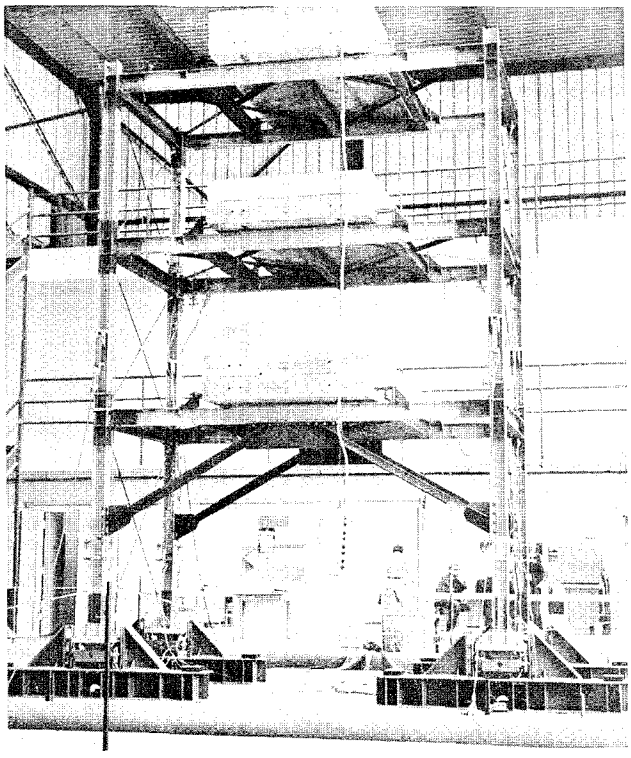


FIGURE 3—Steel frame modified for uplift test.

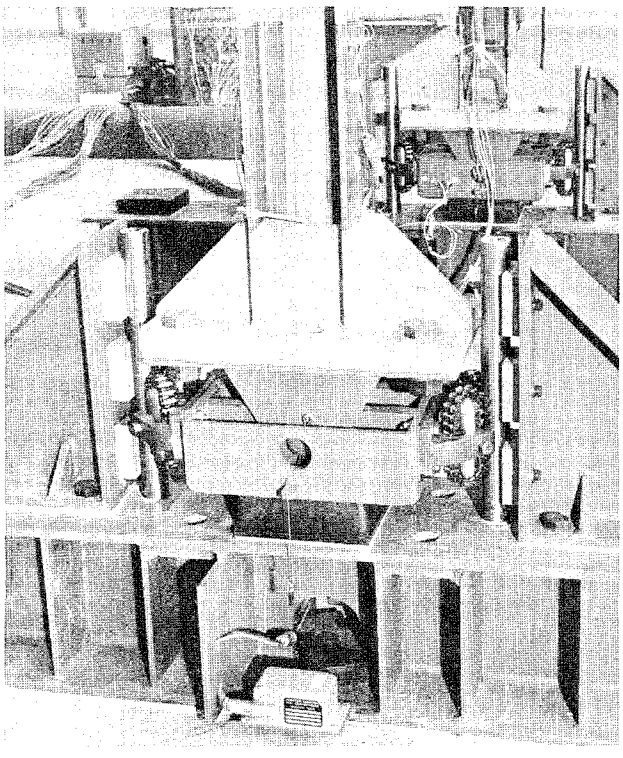


FIGURE 4—Uplifting device at column base.

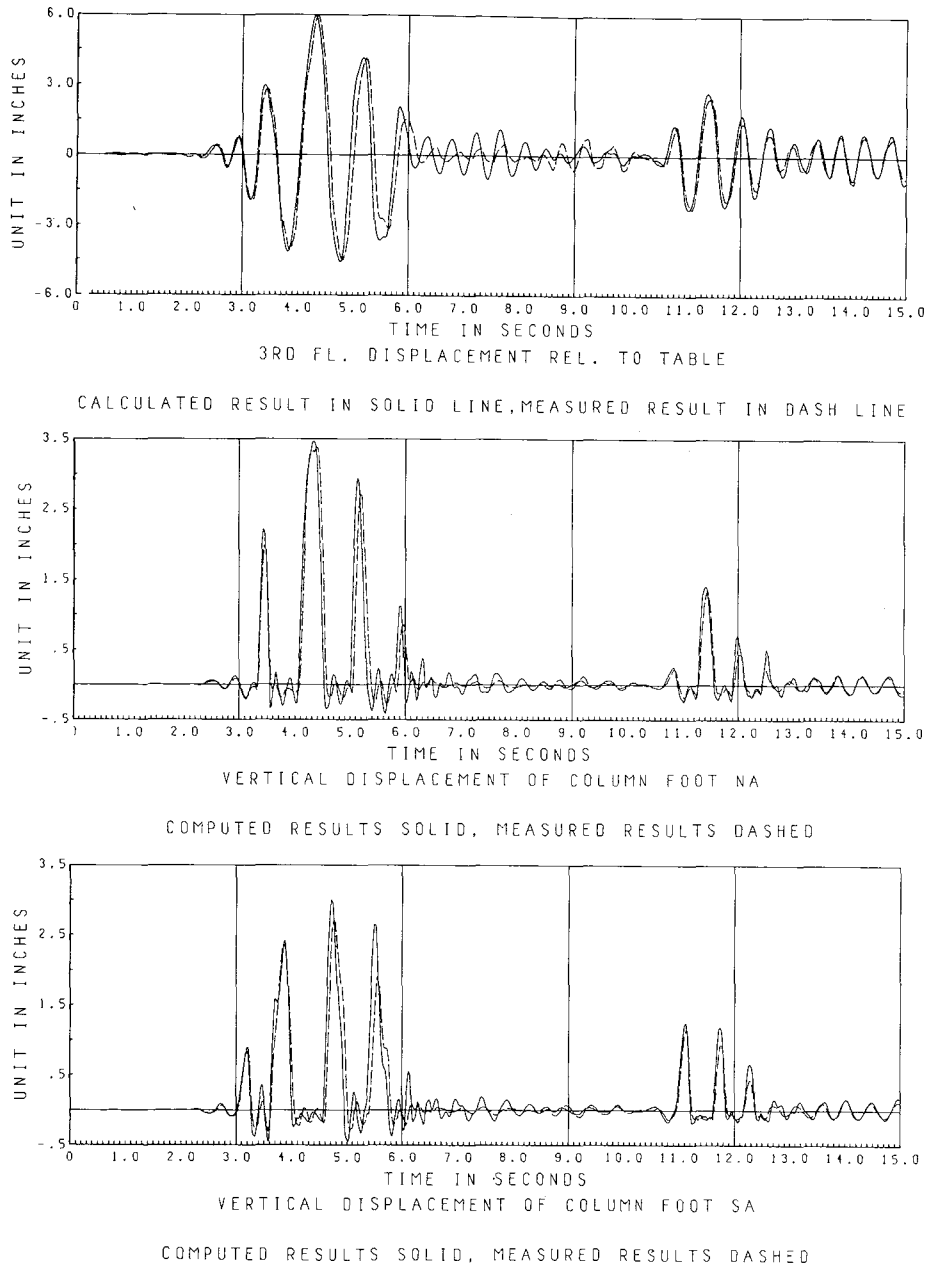


FIGURE 5—Frame displacement response to earthquake.

wave motions, hydrodynamic pressures, and internal stresses in the tank shell. Some results from a typical test are shown in Fig. 8. Of particular interest is the comparison of the acceleration record applied by the shaking table (Graph "a") with the pressure history (Graph "b"). These are very similar in character (noting an arbitrary sign reversal), but a harmonic oscillation clearly is superposed on the acceleration effect in the later stages of the pressure record. The source of this oscillation is very evident in Graph "c," which depicts the wave motion in the tank; thus, the pressures are seen to depend on both the input accelerations and on the wave sloshing motion.

A feature of the response of tanks which are not clamped at the base is the tendency for the base to lift off the foundation, as indicated by the uplift record (Fig. 8d). This uplift occurs around only a portion of the base, and is associated with out-of-round distortions of the top rim, as shown in Fig. 9. Sketch 9a shows the top rim deflected shape at an instant of severe uplift, and 9b shows the vibrating shape that results from this type of excitation.

From the practical design point of view, the most crucial question raised by these test results is whether design procedures based on the approximate theory lead to designs which are both economical and safe. Clearly

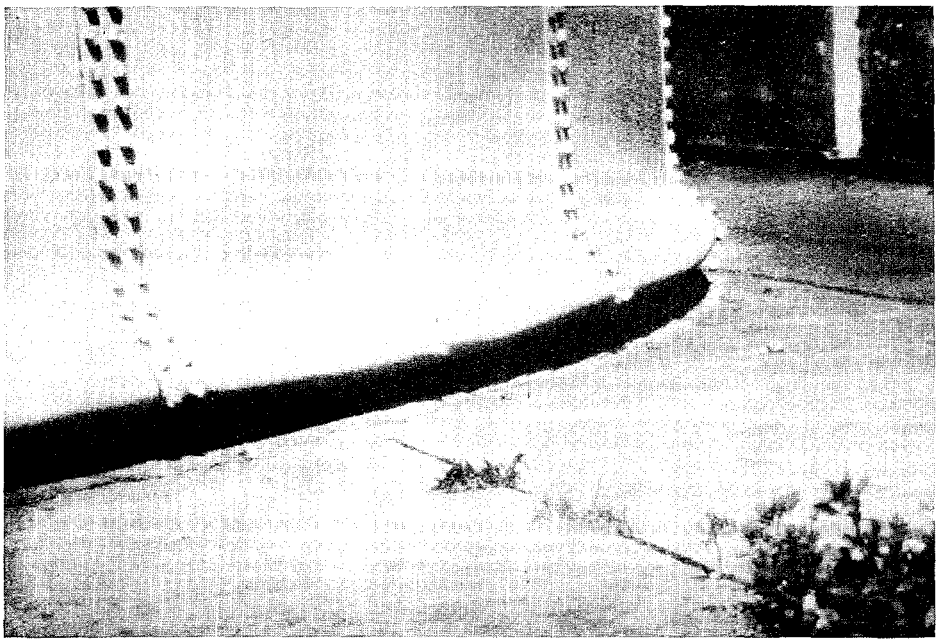


FIGURE 6—Tank buckled during Managua earthquake.

the response is not that of a rigid tank, but the comparison shown in Fig. 10a, of the hydrodynamic pressures predicted by the theory with the pressures observed for a tank with fixed base, demonstrates that, for this case, the essential response behavior is predicted quite well. On the other hand, where the tank is free to uplift, and therefore incurs much greater dynamic distortions, the actual hydrodynamic pressures deviate greatly from the predictions, as shown in Fig. 10b. Thus, it is not likely that tanks which are free to uplift can be designed adequately by the rigid tank theory. It is the purpose of this research effort to formulate improved design procedures based on the behavior mechanisms observed during the test program.

CONCLUSION

These two examples are illustrative of how the earthquake simulator serves the engineering design profession by demonstrating the performance of structural systems during earthquake excitation. The purpose of

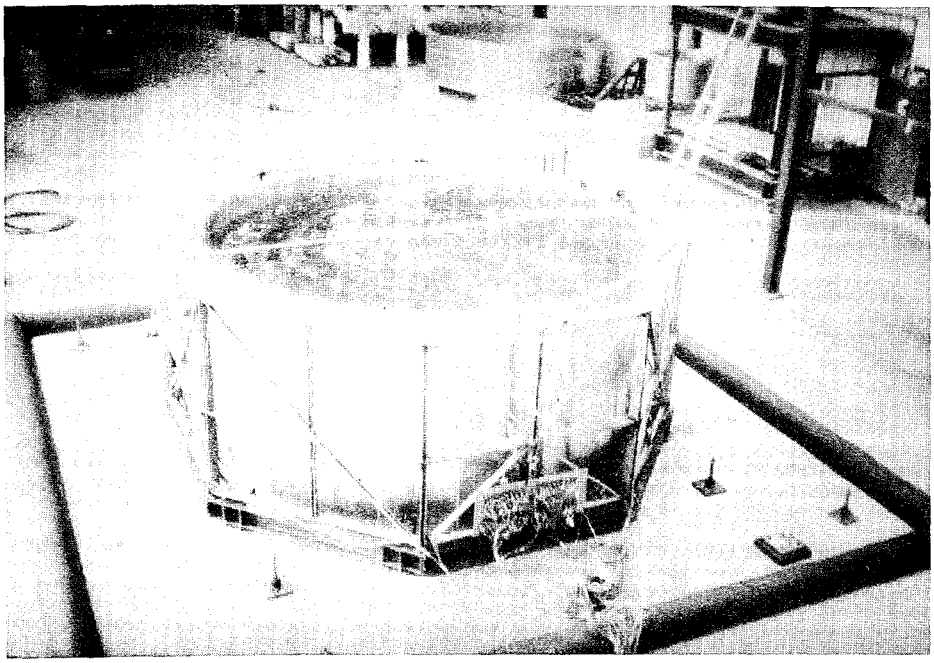
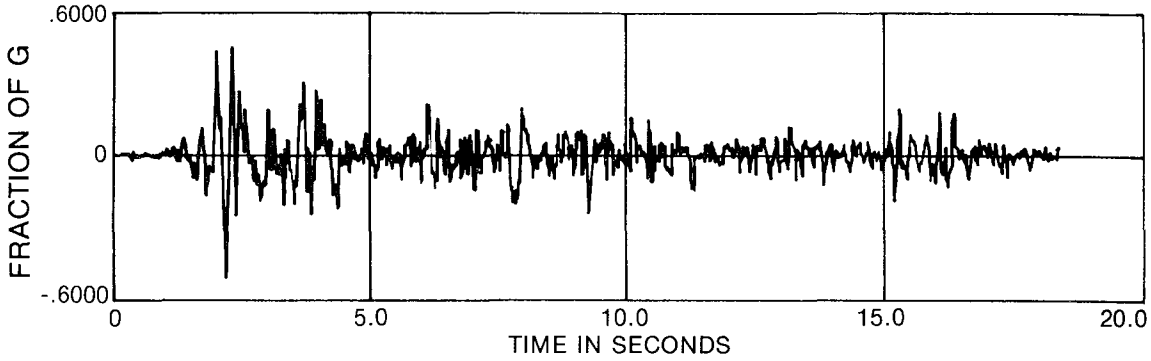
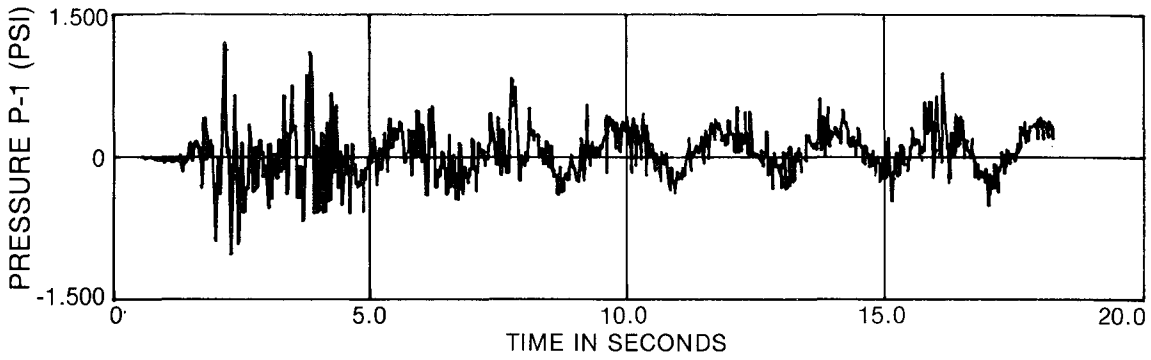


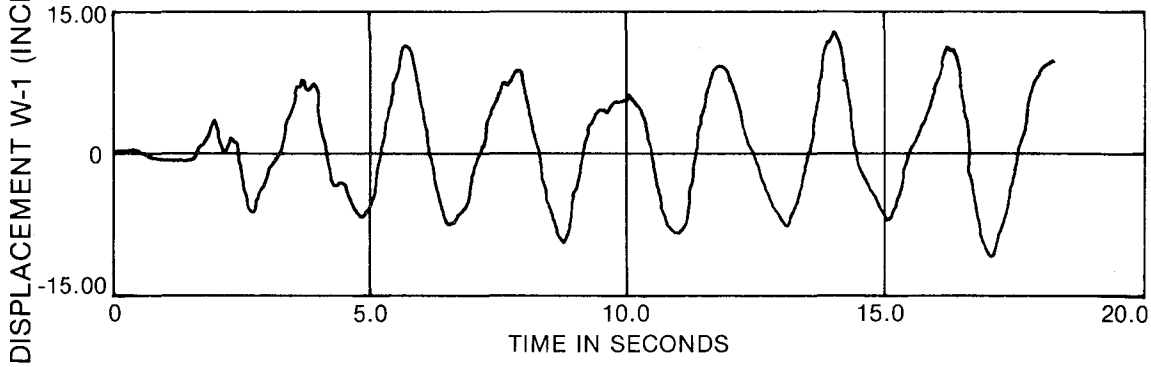
FIGURE 7—Six by 12-ft. tank on simulator.



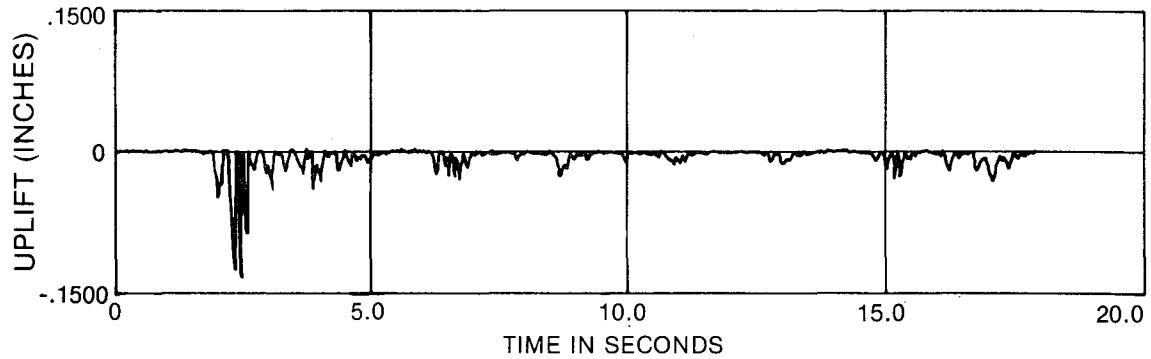
a. INPUT ACCELERATION DUE TO EL CENTRO 1940 (N-S)



b. PRESSURE RESPONSE AT GAGE P-1 (BASE FIXED)

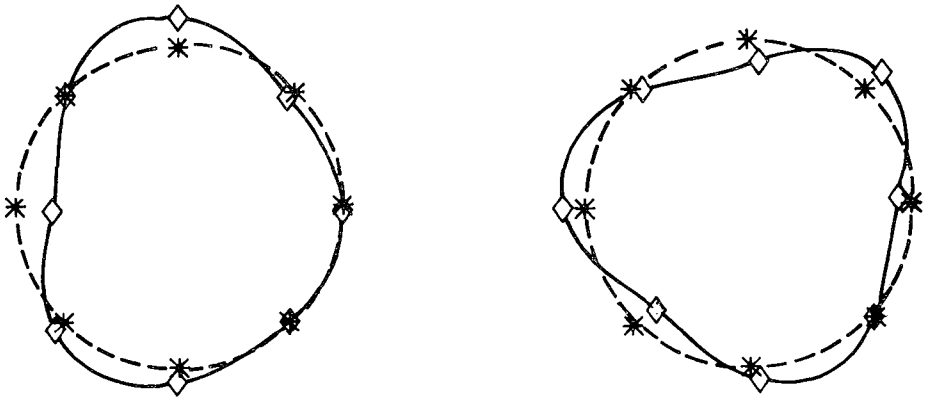


c. WATER SURFACE RESPONSE AT GAGE W-1 (BASE FIXED)



d. UPLIFT RESPONSE AT POINT B (BASE FREE)

FIGURE 8—Measured tank performance during test.



a. 2.5536 SECONDS b. 2.7264 SECONDS

FIGURE 9—Deformations of tank top rim (base free).

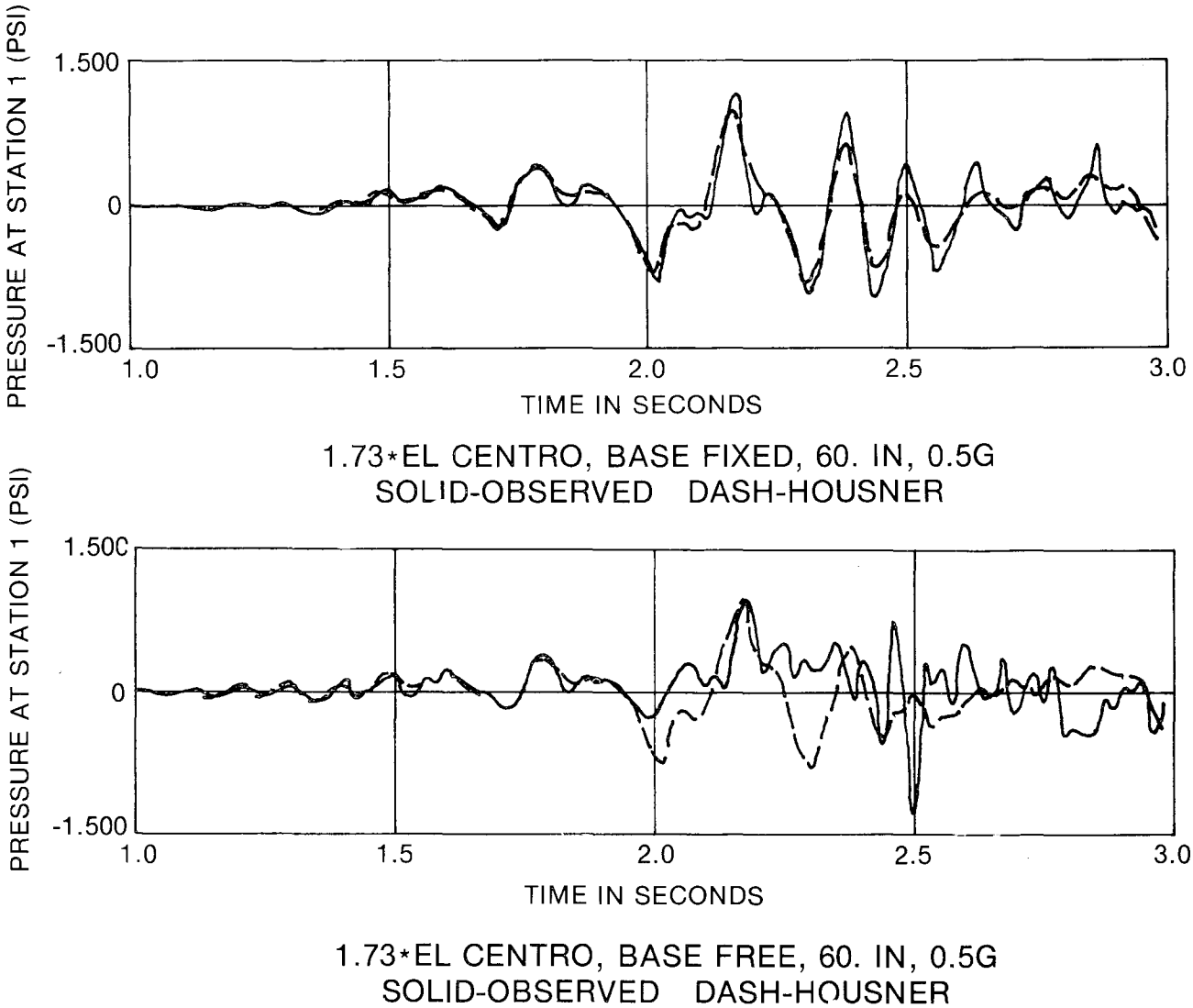


FIGURE 10—Comparison of observed and calculated hydrodynamic pressures.

such tests is not merely to prove if a specific design is satisfactory, although the results give that information. The more important result is detailed data describing the structural response, which can be used to test the adequacy of proposed analytical procedures. After such mathematical analysis methods have been verified, they can be used to predict the behavior of a wide range of similar structures, thereby avoiding the need for further experimentation with that type of structure.

The earthquake simulator facility has been in operation for over three years, and has been continuously scheduled for tests of a variety of different types of structures. Among the more important projects have been studies of two-story reinforced concrete frames which were planned to demonstrate the failure mechanisms of such structures, and to provide data for improving computer programs which evaluate the degree of damage to be expected in them during severe earthquakes. These tests already have demonstrated the great seismic resistance and ductility of well-designed reinforced concrete structures; further testing is under way to examine the behavior of structures which are not so well designed, such as the many existing buildings which were built before current seismic code requirements were imposed.

Another project was the investigation of the cause of the collapse of a very large highway overcrossing structure during the San Fernando earthquake of 1971. A 1/30 scale model of the principal portion of this structure was tested on the earthquake simulator subjecting it to a base motion which was a scaled replica of the motions that were assumed to have occurred in the field. From these experiments it was evident that the temperature expansion joints in the bridge deck were the weak elements of this design, and the research led to improved expansion joint design details as well as to a very effective computer program for predicting the earthquake response of arbitrary long-span deck girder bridge structures.

Other studies which are planned for the near future include evaluation of the seismic behavior of steel warehouse storage racks, which have been damaged extensively in past earthquakes, and evaluation of the performance of diagonally braced steel frame buildings, a type of construction which has proved to be very efficient in non-seismic regions but which is generally avoided by design engineers in earthquake areas.

The earthquake simulator facility plays a significant role in earthquake engineering research. However, some problems are not amenable to this type of experimental investigation. One important aspect of dynamic earthquake behavior which cannot be included in a shaking table study is the influence of foundation flexibility; no effective procedure for including this "foundation-structure interaction" mechanism is presently available. Another factor which is difficult to include in a shaking table test is the contribution of nonstructural components to the seismic performance of a building. Features such as exterior cladding or window-walls and interior partitions generally are not considered in analytical predictions of earthquake response because their contribution is difficult to evaluate. It is equally difficult to include such components realistically in a test structure designed for the 20-foot shaking table.

In spite of its limitations, however, the earthquake simulator facility provides a unique capability in the field of earthquake engineering research, demonstrating the seismic behavior of complex structures and making possible the development and verification of analytical procedures for predicting their performance.

Transferring Earthquake Research into Practice

Robert D. Hanson
Chairman, Department of Civil Engineering, University of Michigan.

The earthquake engineering research program supported by RANN has many practical applications. These occur at many levels of utilization and interact through many different organizations. These applications range from the use of hard data such as earthquake accelerograms and building motion measurements to educational programs and advisory service on public policy decisions. Specific activities to be discussed are design provisions for regulatory code adoption and revision, computer programs for structural analysis, building behavior and design criteria, stronq motion data, criteria for seismic zoning, post-earthquake response and recovery, and special organizational efforts to disseminate information.

Specific RANN projects will not be discussed. The primary emphasis is to report the diverse interaction and transmission of information gained from these research efforts to current use.

As seen from the preceding presentation, efforts to reduce damage from earthquakes must encompass a broad range of activities and utilize personnel from all segments of our population. For purposes of my discussion this morning, I would like to divide the personnel involved in reducing the disruptive effects of earthquakes into three categories. First, the public official will be defined as a governmental employee whose concern is for many members of a community or population and not restricted to one particular client or location. Next, let me define the design engineer as a private professional whose services are employed for a specific project at a given location for a client. Thus his concern with earthquake effects are less general than those of the public official. Third, let me define the researcher as an individual who is primarily interested in generation of basic data. These data will be used by the researcher for improving decision and design procedures, but will not be applied to a specific project, location, or for arriving at a specific decision. The distinctions among the definitions of these personnel are artificial and arbitrary; in fact, one person may fulfill all three functions at different times during the same day. However, in the context of information transfer it is more convenient to think of these as being three distinct groups, and the necessity of transfer of information among them to effectively reduce the damage caused by earthquakes becomes clear. Support by NSF/RANN has contributed significantly to increasing the amount of information transfer, and I would like to illustrate some of the specific cases in which this contribution can be clearly identified.

UNITED STATES GEOLOGICAL SURVEY (USGS) SEISMIC ENGINEERING

The Seismic Engineering Branch of USGS is serving as the primary group in planning and obtaining strong motion earthquake accelerograms from ground sites, dams, and buildings. It coordinates the installation of its strong motion instruments with those of other government agencies and private parties. It collects accelerogram records and distributes digitized data from its instruments as well as from instruments owned by others. This source of data is utilized by public officials, design engineers, and researchers studying the effects of strong motion earthquakes. These records have been used in the past for design of nuclear power plants, off-shore drilling platforms, large dams, high-rise buildings, etc.,

and they have also been used in formulating building code requirements and are currently being used for seismic zoning and risk studies. The recorded motions in buildings are used by the researchers to evaluate the building design and to verify current analytical procedures for use in future building designs.

NATIONAL INFORMATION SERVICE FOR EARTHQUAKE ENGINEERING (NISEE)

The National Information Service for Earthquake Engineering has the responsibility of providing data files of ground motion accelerograms, building motions, and relevant computer programs generated by individual researchers and companies. Through research and development computer software has been made available through NISEE by which the dynamic approach to solving earthquake problems is progressing rapidly. Many researchers, designers, and public officials have obtained computer programs from NISEE which permit them to evaluate the dynamic response of structures subjected to past earthquakes. They provide library facilities for accumulating and disseminating research reports and earthquake information from foreign countries. They provide a convenient and effective source of information for research workers, practicing engineers, government agencies, and foreign researchers. This group is also responsible for the *Abstract Journal on Earthquake Engineering* which summarizes the publications in earthquake engineering subjects from technical periodicals and reports published worldwide. This provides a unique service for the person concerned with earthquake damage and its mitigation.

EARTHQUAKE ENGINEERING RESEARCH INSTITUTE (EERI).

EERI is a nonprofit corporation with approximately 700 members drawn from the most active design engineers, government officials, and research workers concerned with earthquake problems. The members of this organization discuss the needs of earthquake engineering without prejudice to their individual professional disciplines. This broad point of view of the earthquake engineering problem provides a unique capability of coordination of earthquake activities. It provides the primary immediate response to an earthquake. Sending its members to the earthquake sites immediately after the event to provide service and study and then following this with indepth studies in specific discipline areas as appropriate maximizes the amount of information that can be learned from a specific earthquake. With RANN support the EERI is presently using its many years of experience of investigating earthquakes to formalize a response procedure to minimize the effects of the earthquake on the community, to help public officials plan for the emergencies, and to maximize the amount of information that can be gained from a future earthquake. At the present time the EERI is contacting building officials throughout the United States to organize planning and training sessions for public officials and their employees so that officials will be ready and able to respond when an earthquake occurs in their communities. EERI has held and is planning special seminars and conferences throughout the United States to provide education opportunities for practicing engineers, building officials, and researchers.

NATIONAL ACADEMY OF ENGINEERING (NAE)

The National Academy of Engineering has the responsiblity to obtain perishable information such as damage from natural disasters. Its efforts include earthquakes, high winds, and flooding disasters. These immediate field investigations are coordinated with other active groups, for example, EERI in earthquake investigations. NAE also provides study, evaluation, and advisory functions to NSF and other government groups.

UNIVERSITIES COUNCIL ON EARTHQUAKE ENGINEERING RESEARCH (UCEER)

Universities Council on Earthquake Engineering Research consists of active researchers in the earthquake engineering disciplines. The researchers involved in this particular group are primarily university personnel with minor participation by some private research laboratories. One of the primary functions of UCEER is to provide a forum for the researchers to discuss their current activities and near-future activities so that unnecessary duplication of research can be minimized and research results can be more quickly transferred to current use by design engineers and public officials. UCEER also provides guidance to the NSF/RANN in identifying long- and short-range research areas which deserve financial support.

APPLIED TECHNOLOGY COUNCIL

The Applied Technology Council is a corporate subdivision of the Structural Engineers Association of California who were the original authors of the U.S. earthquake-resistant building code. A current effort of the Applied Technology Council with RANN support is the development of a national code for earthquake-resistant design of buildings. This comprehensive code is being written so that it could be adopted by government agencies throughout the United States, and it is anticipated that local government units will also adopt it, because our knowledge of earthquake response and behavior of buildings during earthquakes has increased much more rapidly than the application of this knowledge to design. Thus this building code provides a direct mechanism for speeding the transfer of new knowledge from observation and research to design and construction.

INDIVIDUAL RESEARCHERS, UNIVERSITIES, ETC.

Most of the basic research information needed to reach decisions, develop codes, and minimize the disruptive effects of earthquakes is developed by this group of individuals. Rather than list the individual projects supported by RANN, let me summarize the consequences of the efforts of these individuals and their universities in providing basic earthquake engineering research. In addition to providing basic data used for modifying the building codes and design procedures, they also serve as advisory members on governmental

boards at the city, county, state, and federal levels. They serve as advisers and consultants for various regulatory agencies, including the Nuclear Regulatory Commission. In addition to papers and presentations in technical journals and professional conferences, these persons provide educational training of future researchers and degree engineering courses as well as special courses and short courses for practicing engineers and building officials. They, together with the public officials and design engineers, are participants in visits to destructive earthquakes. The analyses and reports of what has been learned from each earthquake provide the basis for expanding our knowledge of the effects of earthquakes.

I have shown that the activities of NSF/RANN in supporting the transfer of information from the basic data and research into the public decision- and private decision-making functions are manifold. The interaction and intercommunications among concerned individuals with different responsibilities provide an important mechanism for the transfer of this information. Detailed information on specific research projects can be obtained directly from the NSF/RANN Headquarters.

3

SOCIETAL RESPONSE TO NATURAL HAZARDS

3. Societal Response to Natural Hazards

To guide priorities in natural hazard research, RANN initiated a major assessment of problems associated with natural hazards. One of the overriding concerns of the assessment is that research on natural hazards typically concentrates on technologically oriented solutions to problems. This section of material focuses equally on the social, economic, and political factors involved in the reduction of hazards.

One RANN study, which is in its formative stages, is assessing the lasting effects of natural hazards on local neighborhoods and communities. The report analyzes the forces that facilitate or impede adoption of policy measures that would lower the amount of damage from natural disasters (Rossi). Another study demonstrated the consequences of releasing credible earthquake prediction information to several "target" earthquake areas at the federal, state, and local levels (Haas). The performance of alternative insurance and federal disaster assistance programs and the attitudes of homeowners concerning protection against natural hazards were evaluated (Kunreuther).

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Panel Papers

Socioeconomic Aspects of Disaster Preparedness and Recovery

Peter H. Rossi*
Director, Social and Demographic Research Institute, University of Massachusetts.
H. D. Wright
S. R. Wright

Research currently under way at the University of Massachusetts is concerned with two major issues: First, how lasting are the effects of natural disasters of varying severity and origin on local neighborhoods and local communities? The answers to this question are being sought through an analysis of major tornadoes, floods, hurricanes, and earthquakes that occurred between 1960 and 1970, using census data on small areas and local communities. Secondly, what are the forces currently at work that facilitate or impede the adoption in local communities and states of policy measures that would tend to lower the amount of damage and injury from natural disasters, policy measures ranging from fostering insurance purchase to strict land use and building regulations? The answers to this question are being sought through a national survey of local and state elites in a sample of 20 states and 100 local communities. Interviews will be undertaken with governors and mayors, state legislators and city councilmen, state and local agency officials, as well as interested private groups such as leading mortgage bankers, insurance companies, real estate interests, and construction unions. Both projects were started in summer 1976, with results anticipated to be available during 1977 on some of the issues involved.

*Presenter

Among the major aims of public policies concerning natural disasters in the United States are the goal of aiding states and local communities to recover from disasters which they may have suffered and the goal of motivating states and local governments to adopt policies that would lessen the damages and injuries from disasters that will undoubtedly occur in the future. Relief and rehabilitation have long been national goals, fueled by the sympathy and generosity that natural disasters quickly produce. The emphasis on disaster-mitigating policies that go beyond purely engineering measures is perhaps a more recent development, growing out of the realization that more and more of our country's real property and population are at risk and that structural measures such as dams, levees, and more efficient disaster prediction methods are not enough by themselves.

Historically, the major sources of natural disasters have been riverine floods, hurricane winds and accompanying storm surges, and earthquakes. The full costs of these events may never be completely calculated for they include not only the funds allocated for relief and rehabilitation by the federal government—estimated to be $3.5 billion for 1973 alone—but also the costs of insurance premiums paid by households and businesses, the uncompensated for losses of households and businesses, funds from state and local governments, as well as private relief organizations, such as the American National Red Cross, not to mention the costs of interrupted industrial production and other income-producing services.

These two national policy goals—fostering disaster preparedness and providing relief and rehabilitation funds and services—are the background and the motivating rationale for the research project that is currently under way at the University of Massachusetts. My collaborators and I have had a long-standing interest in state and local community decision-making, a thread that ties to these national policy interests a certain amount of expertise growing out of previous research and experience in similar areas.

It would be less than graceful for me not to acknowledge that indebtedness my colleagues and I have toward Gilbert White and Eugene Haas for their monumental survey "Assessment of Research on Natural Disasters." The general outlines of our projects were laid out in that volume and we were inspired to apply to NSF/RANN by

reading that volume. Obviously White and Haas are not to be blamed for whatever errors of conceptualization we have made in translating this portion of the research program they have laid out into specific research designs.

Unlike the other speakers here today, I will not be talking about research that is completed, but about one that has been under way only since July of this year. None of our ultimate findings are available now, although I will be able to say something about findings that have been encountered in the design of the two projects.

The University of Massachusetts research group has been working on two projects, one related to assessing the long range impact of natural disasters and the other concerned with assessing the potential for the adoption of disaster-mitigating policies on the part of state and local governments.

POST-CENSAL AUDITS OF DISASTER RECOVERY PROCESSES

The first project I will describe attempts to provide an empirical description of how long it takes communities and local neighborhoods that have experienced natural disasters to recover and to assess the roles that relief and rehabilitation efforts played in such recovery processes. Although such information would be useful in the planning of relief and rehabilitation efforts, surprisingly little attention has been paid to this question. There has been considerable research and resulting knowledge on the immediate post-disaster period focusing on immediate community response and on the efficacy of relief efforts in the immediate days or perhaps weeks after disaster has struck. The issue we are trying to address is, what will the community be like months and years later? What effects does a disaster have on local economies, growth trends in population, and housing stock?

The strategy of our research project takes advantage of the detailed data already existing in the decennial census. For each of the more than 250 standard metropolitan statistical areas, the census provides statistics on the population and housing stock of small areas, census tracts, containing an average of around 3,000 households. By locating where tornadoes, floods, and damage from hurricanes have occurred in the interval between the 1960 and 1970 censuses, we hope to be able to discern long-term disaster effects by contrasting the tracts that have been hit by disasters with those that have not had those experiences.

The actual process of comparison will be more complicated for we have to discern the effects of different kinds of disasters, of varying severity, holding constant the kind of tracts, described in terms of region, population composition, socioeconomic level, and so forth. Technically, the procedure we will use is multiple regression analysis which we believe will yield estimates of residual effects of disasters on population and housing for neighborhoods, described both in terms of stock and composition, and on the local economies of the communities in which neighborhoods have been hit. Statistics from some 23,000 census tracts from 172 metropolitan areas are currently being processed along with the locations of several hundred major disasters.

We expect to find that disaster effects will be quite complicated. In a pilot analysis of the 1966 major tornado in Topeka, Kansas, which cut a diagonal swath through the city, inflicting damage on more than 1,800 structures, we found that effects still discernible in 1970 were strikingly different in low-income as compared with high-income tracts. High-income tracts showed a spurt in population and housing stock over and above general Topeka trends for such tracts, and low-income tracts showed a marked population decline relative to other Topeka low-income tracts. Extreme caution should be observed in interpreting these findings since they are based only on an event in one city and concern the most severe tornado to hit a major urban place in several decades. Only when we will have processed data from all similar events for the 1960-1970 period will we be able to discern whether these Topeka findings are idiosyncratic or typical of the effects of disasters on neighborhoods of varying socioeconomic status.

We learned several things from our current efforts to assemble data on natural disasters and their location. First, we can provide detailed data on the distributions of natural disasters. Most floods and tornadoes are very minor events in terms of damage and injuries inflicted: for example, of the 1,992 tornadoes recorded in metropolitan areas between 1960 and 1970, only 99 survived the relatively lenient criteria we applied to identify the major events to study in detail. Similarly, of the approximately 3,000 floods in metropolitan areas of which some record is made, only 130 appear to be surviving our screening process. This is *not* to be interpreted that there is *no* serious flood or tornado problem, but only that the problem lies in the very serious but rather infrequent disasters and in the aggregated effects of thousands of minor events. It is the cost of the major disasters and the sum of the costs of the minor ones which constitute the threat of natural disasters in this country.

The previous discussion did not touch upon what we have learned about hurricanes. The dozen that hit the coasts of the continental United States in the period 1960 to 1970 have been serious events, inflicting damages often over several states and sometimes far inland from their initial entry into our borders.

Although it is hazardous at this stage of a research project to guess at final results, I will hazard a few: First, we anticipate that with few exceptions, local neighborhoods and communities snap back rather quickly from the effects of natural disasters, a finding that we believe will be a tribute to the resiliency of the American local community and perhaps as well to the relief and rehabilitation efforts of federal, state, and local governments. Secondly, we expect to find that long-term effects are discernible only in the largest natural disasters, a finding that suggests that there is some need for considering rehabilitation efforts that go beyond the immediate post-disaster period for large-scale disasters.

THE POTENTIALS FOR STATE AND LOCAL DISASTER MITIGATION EFFORTS

In contrast to the project just described which is aimed at understanding the past, our second project is con-

cerned with the present and the future. It is designed to assess the potential for the adoption of disaster-mitigating policies by state and local governments.

The policy background for this project is the growth in our understanding of the nature of natural disasters, in our ability to make responsible disaster forecasts, and in our development of structural and nonstructural measures that would appreciably lessen the damage and injuries therefrom were natural disasters to strike. There is a discontinuity between our knowledge in this last respect and our performance. There are many things that states and local governments can do that would tend to lessen damage and injury. Structural remedies can play an important role: Flood control dams and levees lining waterways can help to contain flood waters. The application of current engineering knowledge to the construction of buildings in earthquake-prone areas or on flood plains can lower property risks. But nonstructural poliicies may also play as important or in some cases a more important role in mitigating the effects of disasters. It makes little sense to have an accurate forecasting system, if forecasts are not translated into warnings followed by appropriate actions such as evacuating populations. Long-range land use policies that restrict occupancy of flood plains and high seismic risk areas may do more to lessen the effects of floods and earthquakes than any other measures, and so on.

While the federal government may provide incentives to states and local governments to adopt such policies and to enforce them, it is still up to state and local initiatives to take advantage of such incentives as are provided in the Flood Insurance Program or in the planning provisions of P.L. 93-288. Of course, planning is not enough: Only if plans are followed by policy, can there be any reasonable effect. Furthermore, policies are not enough: Implementation has to take place for policies to have an effect.

The research strategy to be followed in assessing the potential for adoption of disaster-mitigating policies rests on the obvious observation that policies are enacted by those who are at the helms of state and local governments. We plan to interview state and local elites—defined as persons holding positions that involve decision-making authority or holding positions in organizations that have a presumed stake in decision-making concerning disaster-mitigating policy. On the state level we plan to interview governors, state legislators, heads of appropriate state agencies, representatives from insurance companies, mortgage bankers, the construction and real estate industries, leaders in local chapters of the Red Cross, and perhaps even conservation groups. On the local level, we plan to interview mayors and city councilmen, heads of municipal departments, including planning and building inspection, as well as persons from local mortgage lenders, construction companies, real estate brokers, and similar groups.

A sample of 20 states has been selected with states weighted according to levels of risk from the four natural disasters: floods, hurricanes, tornadoes, and earthquakes. This sample represents the population at risk to such disasters rather than the population as a whole with states having low levels of risk and small population being under-represented in the sample. We are in the process of selecting 100 local political jurisdictions using the same weighting procedure. The local political jurisdictions will represent the counties or municipalities that have relatively large populations and high levels of risk more heavily.

Interviews with persons holding designated positions within state and local elites will cover a variety of topics, each related to understanding the forces that facilitate or impede disaster-mitigating measures. We will ask each person to estimate the risk his or her state or local community bears with respect to the four disaster types. We will also get his or her approval or disapproval of disaster-mitigating policies, probing especially into the individual's perceptions of the costs and benefits of adopting such policies. We will also try to construct what are the forces opposed or in favor of specific types of disaster-mitigating policies. For example, what is the state or local line up of interest groups that favor or oppose flood plain land use regulations?

Since we are at the start of the elite project, very little can be said about findings at this time. However, we can indicate what we believe would be the utility of our findings. It may well be the case that the major obstacle to the adoption of major disaster-mitigating policies is that elites are not aware of the objective risks faced by their state or local communities; a pattern of optimistic denial may characterize their stance on such issues. Or, it may well turn out to be the case that there are many interests opposed to such policies, but few champions, so that decision-makers perceive that they have more to lose than to gain by supporting such policies. Each of these possible findings has implications for federal policy. For example, a pattern of optimistic denial might be best countered by a campaign to diffuse more widely among decision-makers what is already known about levels of risk, and so on.

CONCLUSION

Little can be said at this point that would be a concluding statement for this presentation. What I have described is a project that is in its beginning phase. The best I can do is to state that the existence of this research program indicates a commitment of the NSF/RANN program to more than technological fixes, to an understanding of the social and political aspects of disaster policy, and to a belief that beyond the remedy is the question whether the patient will cooperate enough for the remedy to be taken in dosages large enough to have a palliative effect.

Socioeconomic and Political Consequences of Earthquake Prediction

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The research is an effort to outline the primary consequences of an emerging technology—earthquake prediction. Starting with two urban areas, potential "targets" of a scientifically based earthquake prediction, data were gathered from the following: seismological organizations conducting research on earthquake prediction; large news media organizations; federal and state agencies and legislative leaders; large business firms having interests in the "target" areas; local government units; local business firms; and a sample of families. Data were also analyzed from several "predicted" events in the United States, Japan, and China.

Assuming a credible earthquake prediction, the findings indicate that there will be a drastic reduction in deaths and injuries if a damaging earthquake occurs approximately as predicted. Further, property damage will be appreciably reduced as a result of actions triggered by an earthquake prediction. A third important finding is that with an extended lead time the community will suffer significant social disruption and decline in the local economy. This consequence is most likely when the time between the release of a certified prediction and the expected date of the earthquake is a year or longer.

*Presenter

In the spring of 1975 the University of Colorado's Institute of Behavioral Science began research on the probable consequences of scientifically based earthquake prediction. The specific focus was on how the first few predictions would affect the citizens and organizations of "target" communities.

WHAT MAKES A PREDICTION BELIEVABLE?

The first step in the research process was to determine what about an earthquake prediction would make it more or less believed. We conducted a series of 35 interviews with a carefully drawn sample of business and government executives throughout the state of California, discussing with them their views of the dimensions of a potentially credible earthquake prediction. How important is the source from which the prediction comes? Would a highly specific earthquake prediction be more believable? Would the expressed level of probability or certainty (e.g., 80 percent probable) be a significant consideration? Would the actions of other organizations in response to the prediction make the prediction itself more credible? These and other considerations were discussed at length. The findings served as a basis for the next step in the research process. A summary of the findings appears in the box.

WOULD AN EARTHQUAKE PREDICTION MAKE A DIFFERENCE?

SAN FERNANDO EXECUTIVES GIVE THEIR VIEWS

San Fernando, California, business and community leaders have a realistic idea of the loss and disruption that follow an earthquake, since they experienced a severely damaging earthquake in 1971. We held extended discussions with 22 San Fernando organization executives to

DIMENSIONS OF A CREDIBLE EARTHQUAKE PREDICTION

*** Reputation of Prediction Source
** Agreement among Seismologists/Scientists
** Expressed Certainty or Probability
** Specificity Regarding Location
* Estimate of Magnitude
* Specificity Regarding Time of Occurrence
* Length of Lead Time
Actions of Other Organizations

find out what they think they would have done differently had they believed in advance (because of a credible earthquake prediction) that the February 1971 earthquake was coming. We also inquired as to their organizations' probable actions and constraints if they were to now get a prediction with a two-year lead time. They were also asked about their response to a five-year lead time.

Their answers were thoughtful, comprehensive, and apparently quite realistic. They laid particular stress on the need for additional information, and said their organizations would respond to a prediction with policy changes, reallocation of resources, and new contractual arrangements with other organizations. Their answers provided us with a veritable catalog of organizational decisions and actions which would be prompted by a credible prediction for a damaging earthquake.

Having achieved an understanding of what makes an earthquake prediction credible and the range of responses which organizations are likely to make to credible predictions, we began the core effort of the research project.

THE IMPACT OF AN EARTHQUAKE PREDICTION ON GOVERNMENT, BUSINESS, COMMUNITY

We followed a step-by-step process in collecting data from one category of organizations after another. From seismologists we obtained estimates of what would be the characteristics of the first scientifically based earthquake predictions and how such predictions would be released. We also got their estimates of where in California the earliest predictions are most likely to come.

Drawing upon the many possible predictions that might come in the future, the seismologists helped us formulate two "prototype" predictions. The first, dubbed scenario "A", would involve a five-month lead time, an expected 6.3 Richter magnitude, and a 50 percent probability expression. The second, scenario "B", would involve an expected 7.3 magnitude and a three-year lead time (two years following an official prediction).

LARGE NEWS ORGANIZATIONS

After completing the discussions with the seismologists, we queried executives of eight large news organizations (newspapers, television, and radio) operating in California regarding how their organizations would handle each of the two prototype earthquake predictions, scenario "A" and scenario "B." After lengthy informal discussions covering a list of potential issues which the predictions might raise, we summarized the tentative findings and incorporated them into the two scenarios. Follow-up interviews with the executives provided an opportunity to revise and fine-tune the news media portions of the scenarios.

The revised scenarios represented a summary version of the findings up to that point in the study.

STATE AND FEDERAL AGENCIES

We then selected a sample of 31 federal and state agencies which would have involvement of some kind in the event of a credible earthquake prediction. The scenarios were sent in advance to the appropriate officials within each organization, following which we conducted informal, in-depth discussions with them. They were asked to assume the "facts" incorporated in each scenario covering the characteristics of each of the two prototype predictions and the descriptions of news media treatments. A checklist of issues which the organizations might have to face following either of the two prototype predictions served as the basis for the discussions. The number of officials interviewed within each agency ranged from one to six.

Based on the tentative findings from these informal discussions, we wrote new sections for each scenario covering state and federal agency reactions. The same officials reviewed these new sections and, after follow-up interviews, suggested revisions and refinements. Finally, the officials answered 31 specific questions about changes their agencies would make in policies, programs, emphases, expenditures, personnel, etc., in response to scenario "A" and scenario "B."

These same 31 specific questions were asked of all organization officials and executives in subsequent interviews.

The same procedures as described above were used in collecting data from four additional samples of organizations: large business firms, local governmental agencies from two metropolitan areas in California, and local business firms from the same two areas. In addition, we had discussions with local news organizations in these two areas.

LARGE BUSINESS FIRMS

We selected a sample of 37 firms representing the largest and most influential firms operating in California. The firms selected represent banking, savings and loan associations, insurance, engineering, construction, real estate, wholesaling, retailing, manufacturing, transportation, communication, utilities, land development, and even some conglomerates. (Labor unions are also included in this sample.) Most are California-based, although many operate in other states, and some are international in scope. Several are among the 50 largest corporations in the United States.

LOCAL ORGANIZATIONS: GOVERNMENT AND BUSINESS FIRMS

Earlier, the seismologists had helped us select two areas which they saw as "likely candidates for an early earthquake prediction," one in southern California and one in northern California. In these two urban areas we selected 41 local units of government which would be involved extensively in the event of an earthquake prediction. Examples include departments of public works, finance, planning, welfare, police and fire, as well as schools, hospitals, prisons, and publicly owned utilities.

In the same urban areas the sample of 38 local businesses included banks, insurance agencies, savings and loan institutions, development companies, real estate agencies, manufacturers, wholesalers, retailers, and property management firms, among others.

FAMILIES

We selected a scientific sample of 246 families in one of the two areas, and collected data from them following the same procedures we had used with business executives and government officials. Using a limited number of the major findings by now reflected in the scenarios, we developed a special audiovisual device to present mini-scenarios to the adults in each family. These mini-scenarios served as the basis for informal discussions and for later followup interviews.

The questions used dealt with a wide range of possible reactions to the earthquake prediction itself and with probable family responses to the actions being taken by organizations. Examples include possible changes in employment, residential location, spending and saving patterns, attempts to buy or sell real estate, purchases of insurance and durable goods, special safety measures, and so forth.

PRINCIPAL FINDINGS HAVING POLICY RELEVANCE

Our research indicates that, assuming a credible earthquake prediction, there will be a drastic reduction in deaths and injuries if a damaging earthquake occurs approximately as predicted. Property damage will also be reduced appreciably by the precautions made possible by an accurate prediction. However, another important finding is that if the prediction provides an extended lead time, the "target" community will suffer significant social disruption and decline in the local economy, especially if this lead time is a year or longer.

Reduction in Casualties

It is clear that there will be a considerable reduction in the number of people in the area of the expected earthquake. That trend alone will likely reduce the population at risk by at least 50 percent. But there will be a number of other responses to the earthquake prediction which, taken as a whole, will reduce the risk even further.

In the broadest sense, the responses to the prediction can be categorized as physical adjustments and socioeconomic adjustments. The physical adjustments range from simple precautions to reduce the likelihood of injury, such as securing bookcases to walls, or storing items so as to eliminate toppling or shifting, to major structural modifications in buildings and lowering of water levels behind dams. Figure 1 summarizes the types of physical adjustments which can be employed when there is an extended lead time.

Our findings suggest that up to three-quarters of the businesses and government agencies in the "target" area would make some effort to assess the vulnerability of their buildings, equipment, and inventory as a result of an earthquake prediction, and would take appropriate precautions. Similar measures would be taken to reduce the hazards related to industrial processes. About one-half of the families interviewed would also take such precautions, with particular emphasis on nonstructural measures to reduce the risk of injury or death.

The cessation of new construction in the "target" area will reduce casualties in two ways. The fewer the number

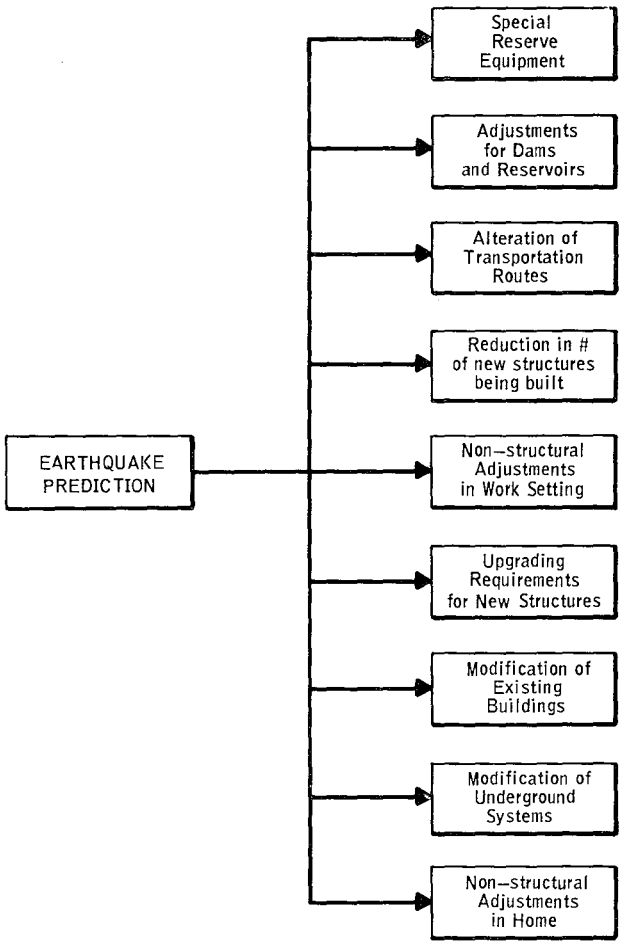


FIGURE 1—Types of Physical Adjustments Leading to a Reduction in Casualties

of structures in place in the harder-hit areas, the fewer the people at risk. Also, partially completed buildings are more susceptible to collapse, and more likely to cause injuries, than completed structures. There will be few, if any, such partially completed buildings in the area by the time of the earthquake.

Decisions regarding some physical adjustments will be made in the public sector, e.g., alteration of transportation routes and structural modification of public buildings. Other matters will be decided in the private sector, e.g., protection of inventory and reduction of hazards related to industrial processes. All will cost money and, in some instances, the costs may be considered unacceptably high, as in the case of major structural modifications to older, larger public buildings. Local government and some smaller, strictly local businesses will have reduced incomes just as they must decide whether or not to make costly physical adjustments. Thus, in many instances, socioeconomic adjustments such as vacating buildings temporarily will be used in preference to more costly physical alterations.

Another factor working against widespread recourse to physical adjustments is the doubt expressed by many executives, officials, and citizens about the state of the art

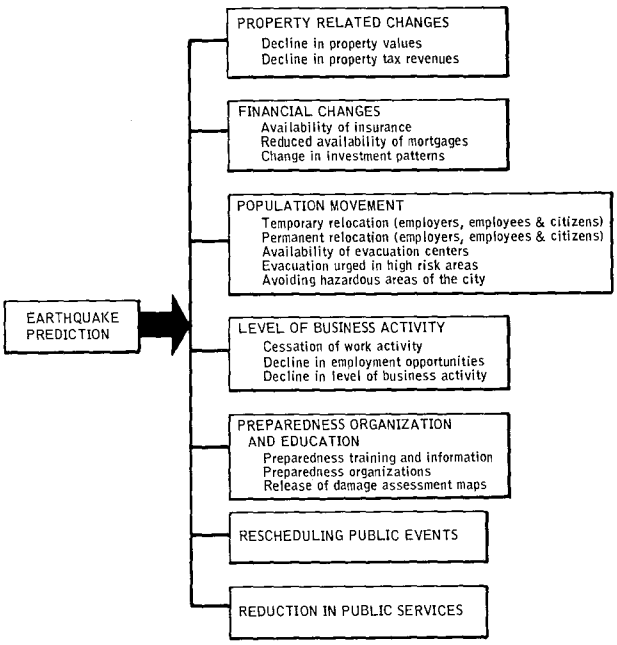
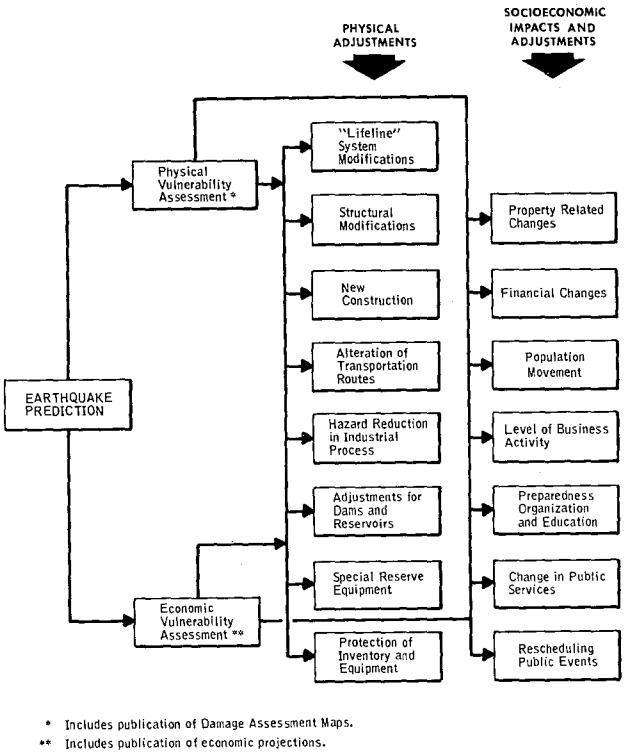


FIGURE 2—Types of Socioeconomic Impacts and Adjustments to an Earthquake Prediction



* Includes publication of Damage Assessment Maps.
** Includes publication of economic projections.

FIGURE 3—Links Leading to Reduction in Casualties

in earthquake prediction and in earthquake engineering. They fear that the earthquake may be of a larger magnitude than predicted and/or that the best judgments of the best engineers may not be good enough—that even if a building is strengthened according to an engineer's recommendation, it may still suffer extensive damage because of a lack of precision in the basic knowledge of earthquake engineering.

Nevertheless, many engineering firms which have lost business because new construction has ceased will offset this loss somewhat with work in evaluating structures and in designing changes to make them more earthquake-resistant.

Socioeconomic adjustments leading to reduced risk of casualties are numerous. Figure 2 summarizes the major socioeconomic responses and adjustments that will occur.

The major socioeconomic responses to an earthquake prediction are so interrelated that even those which at first glance might seem to have no bearing on risks of death and injury do, in fact, affect such risks. For example, nonavailability of earthquake insurance following the official prediction triggers changes in mortgage availability, property values, investment patterns, and employment opportunities. These changes lead to a reduction in tax revenues for local governments, which in turn leads to a reduction in public services; the curtailment of public services impels more people to leave the area, and thus fewer people are exposed to the risk of death and injury.

Note again that there are both private sector and public sector decisions and that the consequences of those decisions flow both ways, each sector affecting the other. If governments urge evacuation of higher-risk areas, local businesses will be negatively affected, but more lives available, this will reduce property tax revenues and, ultimately, have a negative effect on public services, but it will also have the effect of inducing more people to leave for safer areas. Shutdowns and layoffs by area employers will depress the local economy, but will also encourage temporary relocation, and thus save lives. Only a few significant decisions will discourage relocation; most will encourage it and thus reduce the risk of death and injury.

Figure 3 displays in simplified form the links involved in the physical and socioeconomic adjustments leading to reduced casualties.

Reduction in Property Damage

Upgrading the earthquake-resistance of structures is, of course, one of the most important responses for protecting property. The public sector will carefully examine underground utility lines, power and sewage treatment plants, communications facilities, and special structures such as dams, bridges, and overpasses. Action may be taken to increase their earthquake-resistance, and to decrease damage due to their failure or collapse. Both the public and private sectors will take special measures to secure equipment and inventory; about one-half of the area's residents are expected to take similar precautions in their homes. The near-absence of new construction should nearly eliminate the special risks associated with partially completed structures.

Businesses and government agencies will reduce their vulnerable inventories to a minimum as the time for the earthquake approaches. A few will relocate permanently outside of the threatened area, but most who engage in relocation activities will merely temporarily relocate

some, if not most, of their equipment, records and inventory. This will significantly reduce the property at risk.

Similarly, families worried about possible damage to expensive household items will postpone purchasing such items until after the expected earthquake; about two-thirds of families interviewed indicate they will delay such purchases. The tightening of credit by lenders will also tend to slow the sale of durable goods, and the shipment of such goods into the "target" area.

More than one-third of all families will move some of their possessions to safer locations, and approximately 10 percent will leave the area permanently. If many employers relocate permanently, of course, that percentage will be much higher.

Some of the major adjustments to an earthquake prediction, their links and consequences for reduced property damage can be inferred from Figure 4.

Disruption of the Local Economy

Many of the physical and socioeconomic adjustments which tend to reduce casualties and property losses will also tend to depress the "target" area's economy, perhaps severely, prior to a predicted earthquake.

Following a credible earthquake prediction, families, businesses, and governmental agencies will try to act in a manner favorable to their own interests. Investors will generally put their money outside of the "target" area, or invest very selectively within the area, on the assumption that this will lower their risk. Development planning and construction in the private sector will first be drastically reduced, and then entirely stopped. Local governments will likewise stop or sharply reduce capital construction projects. (Following the time of the expected earthquake there should be a large pent-up growth potential.)

Routine repairs on buildings in the public and private sectors will drop off before earthquake week, but this will be partially offset by alterations to make buildings more earthquake-resistant. Influenced by the construction industry, business in general will slow its activity, unemployment will rise sharply (especially in the six months prior to the expected earthquake), and local governments will suffer severe declines in sales and property tax revenues. Local residents will cut down on purchases, and income from tourism is likely to fall away to nothing.

A very few firms, mostly large national ones, will move out of the area entirely. Lenders, especially locally-based ones, will protect their investors' interests by limiting credit and being more selective in granting mortgages. Real estate transactions will be sporadic but eventually slow to a trickle. Withholding of mortgage and property tax payments will be minimal.

Taken as a whole and in the absence of planned interventions, the total picture adds up to economic dislocation and social disruption. Planning in advance to cope with the physical effects of an earthquake is one thing. Living with the repercussions of the prediction is something else. There is a sizeable economic and social cost to pay for lowered risk of casualties. We think that the potential dislocation and disruption need not be so massive if wise action is taken in advance of the prediction.

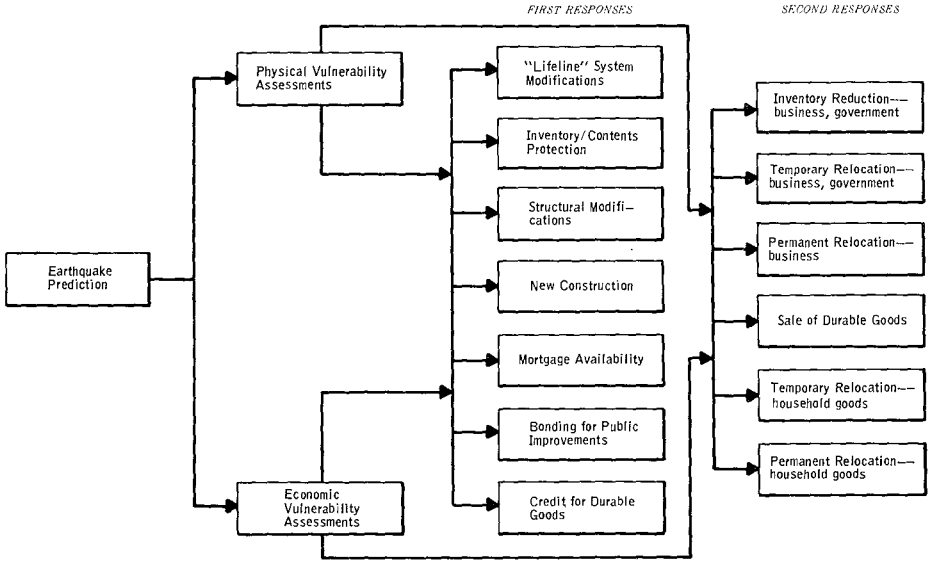


FIGURE 4—Links Leading to Reduced Property Damage

Reducing Losses from Selected Natural Hazards: Role of the Public and Private Sectors*

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This research examines the decision processes utilized by homeowners in coping with natural hazards that could result in some loss to them, but which they perceive as having a small chance of occurrence. On the level of public policy the study is concerned with the appropriate roles of the public and private sectors in offering protection against natural hazards and in providing relief in the aftermath of a disaster.

The primary objective of this effort has been to evaluate the performance of alternative insurance and federal disaster assistance programs through testing alternative models of individual behavior with respect to low-probability events. The two approaches are the expected utility model and a sequential model of choice. Detailed data have been collected through a field survey of 3,000 homeowners in flood-prone areas in the United States and earthquake-prone areas in California. Approximately half of the respondents had purchased flood or earthquake insurance. The field survey has been supplemented by controlled laboratory experiments on insurance. The paper reports the results of the field survey and laboratory experiments and the implications for public policy regarding natural hazards.

RESEARCH OBJECTIVES

How do people determine whether or not to protect themselves against low-probability events having severe consequences? What are the decision processes that they utilize in coping with hazards that could result in some loss to them, but which are perceived as having a small chance of occurrence? These are the main questions investigated by this research supported by NSF/RANN. The specific hazards studied are floods and earthquakes; the primary form of protection examined is insurance. On the level of public policy, our interest is in raising questions regarding the appropriate roles of the public and private sectors in offering protection against natural hazards and in providing relief in the aftermath of a disaster.

When looking at low-probability events, the points of view of the individual and society often conflict. For example, a homeowner residing near a river may picture a damaging flood as having a small probability of occurrence, or he may not perceive his potential property losses to be very large. Yet on a national level, the probability of severe flooding somewhere next year is relatively high, and the expected aggregate costs are substantial.

A central factor makes this problem socially important. If people do not protect themselves against the consequences of a low-probability event, then society is likely to bear a large portion of the costs following a disaster. For example, few residents of California purchased earthquake insurance prior to the San Fernando quake of February 1971, and hence many of the victims turned to the federal government for relief. Congress then responded with low-interest loans and forgiveness grants. Such behavior raises the following question that has broad implications for public policy: What factors induce individuals to protect themselves voluntarily against the consequences of low-probability events such as floods or earthquakes? To help answer this question, we have collected data through a field survey of homeowners residing in flood- and earthquake-prone areas and from subjects participating in controlled laboratory experiments related to insurance purchase decisions. These data have enabled us to focus on each of the following research objectives of the study:

(1) How well do various models explain choice under uncertainty in the pre-disaster period?

* This paper summarizes the principal findings from an NSF-RANN project "Reducing Losses from Selected Natural Hazards: Role of the Public and Private Sectors" (Grant #ATA73-03064-A03). A more detailed discussion of the results of the study appears in Kunreuther (1976) and Kunreuther et al. (1978). The ideas and results are due to the combined efforts of a number of individuals, notably Bradley Borkan, Baruch Fischhoff, Ralph Ginsberg, Norman Katz, Sarah Lichtenstein, Louis Miller, Philip Sagi and Paul Slovic.

(2) What role can insurance play in enabling individuals to process information and undertake appropriate protective measures for hazard mitigation?

(3) What information and attitudes do homeowners have regarding hazard mitigation and disaster relief measures such as land-use regulations, building codes, and low-interest loans?

(4) What are the physical characteristics of flood- and earthquake-prone areas and the economic and sociological profiles of homeowners residing there?

ORIGIN OF PROJECT

During the period from 1953 to the present, the federal government played an increasing role in providing disaster relief. While the dollar amount of damage from natural disasters has climbed rapidly since the early 1950s, federal financial assistance during this period has grown even more rapidly.

Evidence of increased federal disaster relief through 1973 is provided by comparative data on the Small Business Administration (SBA) disaster loan program shown in Figure 1. The growth of the program is particularly striking in the case of home loans, where both the total number and total dollar values during the most recent fiscal years of the program (1966-1976) were more than 25 times what they were during the first 12 years. Part of this increase may have been the result of a rising trend in damage from natural disasters. But even with this cautionary note, it is striking that the $1.2 billion in loans approved by SBA for victims of the tropical storm Agnes (June 1972) represented almost four times the entire amount allocated by SBA for all disasters between fiscal years 1954-1965.

The National Flood Insurance Act of 1968 is the first positive step taken by the federal government to induce individuals to protect themselves against losses from flood disasters. However, there is substantial evidence that most individuals in flood-prone areas have not voluntarily purchased insurance. For example, Rapid City qualified for flood insurance in April 1971, yet only 29 policies were in force at the time of the June 1972 flood. Analogous behavior was evident in states hit by tropical storm Agnes: only 683 residential policies were sold in Pennsylvania, 2,046 in New York, and 693 in Maryland before the disaster occured.

Turning now to earthquake insurance, policies have been privately marketed by American insurance companies since the early 1900s. Premiums for wood-frame homes in California, which comprise almost all residential structures in the state, average 20 cents per $100 coverage with a five percent deductible clause. A policy can easily be written as an endorsement to comprehensive homeowners coverage. Few California homeowners, however, have purchased earthquake insurance.

RESEARCH INSTRUMENTS

To discover differences between insured and uninsured individuals, a field survey was undertaken in flood- and earthquake-susceptible areas in the United States by the Institute for Survey Research at Temple University. The sampling plan called for face-to-face interviews with 2,000 homeowners residing in 43 areas subject to coastal and riverine flooding, and 1,000 homeowners living in 18 earthquake-susceptible areas of California. Data provided by the insurance industry and National Flood Insurers Association enabled us to design the sample so that half of the respondents had purchased flood or earthquake insurance and the other half had not.

To provide further insight into man's decision processes regarding protective activities, the field survey data were supplemented by controlled laboratory experiments on insurance sales conducted at the Oregon Research Institute. These experiments provided insight into how man's information processing limitations affect insurance purchase decisions.

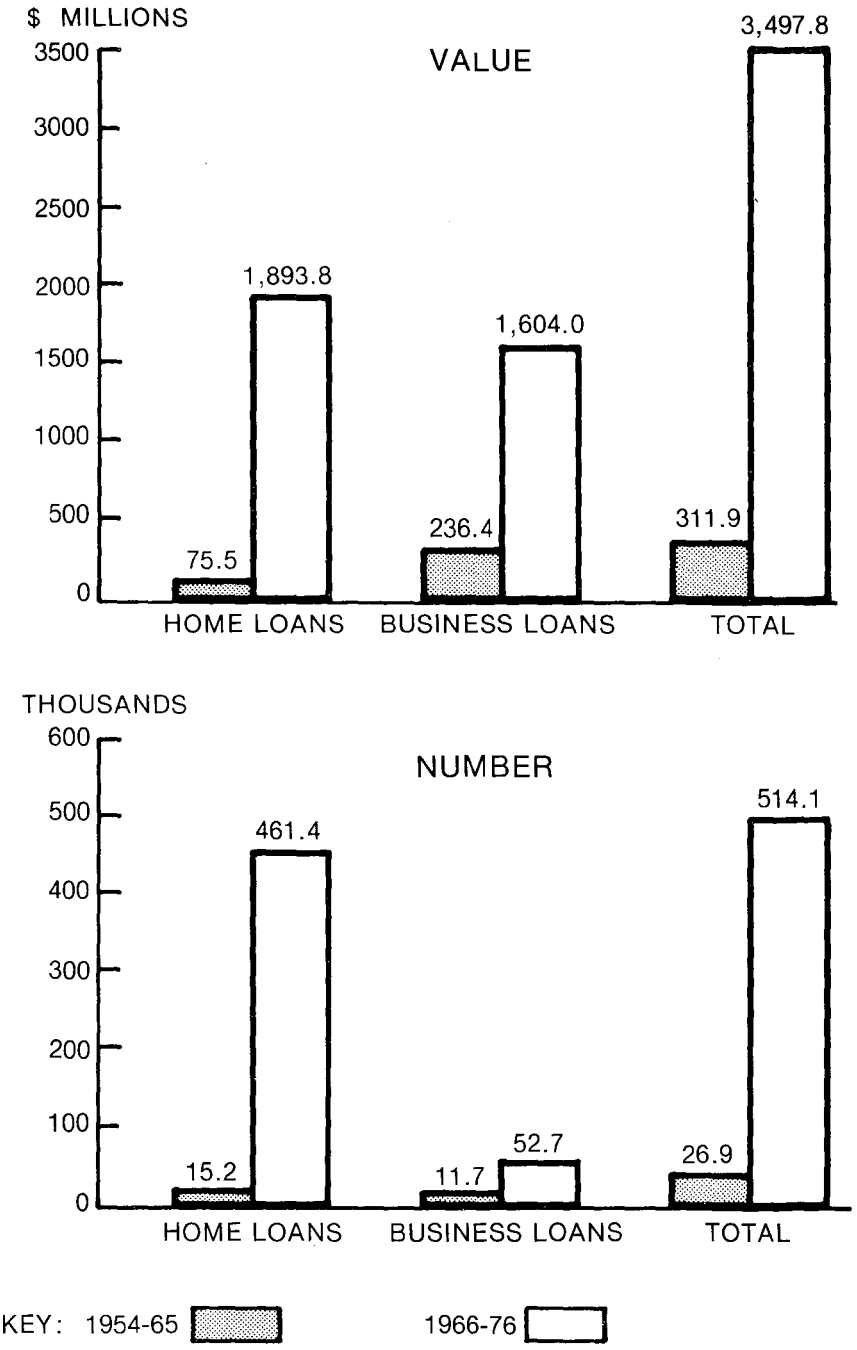
RESEARCH RESULTS

The field survey data indicate that the majority of individuals residing in hazard-prone areas have limited knowledge about the flood or earthquake problem and/or the availability of insurance coverage. A significant number of uninsured individuals are unaware that policies can be bought in their neighborhood, or they are unable to estimate the insurance premium, deductible amounts, potential damage, or probability of a future disaster.

The data also indicate that the majority of uninsured homeowners expect no federal aid should they suffer losses from a severe flood or earthquake. These findings suggest that prior to a disaster most individuals have not thought about whether the government will aid them financially should they suffer severe losses, nor how they can protect themselves. In fact, it may very well be the case that homeowners have not consciously considered how they would recover in the wake of a flood or earthquake.

The behavior of homeowners is consistent with a sequential model of choice. Detailed statistical analysis indicates that viewing the hazard as a serious problem and knowing someone who has purchased insurance are the two most important determinants of the flood or earthquake insurance purchase decision. Furthermore, these two variables have a strong interaction effect. Thus, if someone thinks the hazard is a serious problem and also knows a policyholder, he is more likely to purchase insurance than these variables would imply separately. In quantitative terms, people who know someone and think the hazard is a serious problem have a 55 percent greater chance of having insurance than those who do not know someone and feel the hazard is an unimportant problem.

The controlled laboratory experiments suggest that consumers are unlikely to view the hazard as a problem if the chance of the event occurring is small, even though the resulting losses may be relatively large. This emphasis on the low-probability rather than on the potential damage leads individuals to treat insurance as an investment rather than as a protective mechanism. Our study suggests that the principal reason people do not buy coverage



SOURCE: SMALL BUSINESS ADMINISTRATION, OFFICE OF REPORTS

FIGURE 1—Comparison of Value and Number of SBA Loans, by Category, for Fiscal Years 1954-65 and 1966-76

is because they feel they are unlikely to receive anything back on premiums they would pay.

On the other hand, if the homeowner views the hazard as a problem, either because he has suffered personal losses or as a result of seeing vivid accounts of disasters by the mass media, then insurance is likely to be attractive to him because he is now focusing on the loss dimension. In this case the relatively small premium appears as an attractive investment to him against the potentially large loss from a future disaster.

An additional factor inhibiting the voluntary purchase of flood or earthquake insurance is the time it takes to

disseminate pertinent information. Studies on this diffusion process point to the role of interpersonal contact as a convenient and reliable data source and an important element in the final decision regarding the purchase of a product.

IMPLICATIONS FOR PUBLIC POLICY

What are the implications of the above findings with respect to public policy? If one is to market insurance effectively without making coverage compulsory, then programs must be designed to cope with the following two phenomena implied by the sequential model of choice:

(1) The lack of awareness by individuals of the losses from the hazard and its probability of occurrence.

(2) The lack of awareness by individuals of the availability of insurance and the terms of a policy.

To make individuals more aware of the potential problems arising from the hazard, primary emphasis may have to be placed on the loss dimension, for example, through films and the mass media. There is still no guarantee, however, that such publicity will have any impact on personal action. Two recent films, "The City That Waits To Die" and "Earthquake," graphically depicted the vast death and destruction following a severe earthquake but had little, if any, impact on the sale of earthquake insurance.

The insurance agent may serve a very useful role in increasing people's awareness of flood and earthquake insurance and the terms of a policy. He can initiate contact with homeowners in hazard-prone areas who have purchased other policies from him and inform them of the rate schedule and stated deductible. In the case of flood insurance, he should indicate that premiums are subsidized 90 percent by the federal government on all existing homes and that rates are uniform so a search for the best price is unnecessary.

If most individuals treat insurance as an investment, then one of the principal functions of the agent should be to educate the policyholder that the biggest return on one's policy is not to have any return at all. Unless the homeowner adopts this point of view, he is likely to purchase flood or earthquake insurance only after suffering damage and may then cancel his policy a few years later if he has not received a return on his investment. Today the agent has a limited economic incentive to initiate personal contact with his clients. Commissions are based on an amount proportional to the total premium which, in the case of earthquake and flood insurance, is usually a small amount. One way to increase the agent's interest in marketing coverage would be to raise commission rates on the sale of new policies.

Even if such programs were put into effect, the impact on insurance sales probably would not be very large. Evidence suggests that the acceptance of earthquake and flood insurance is likely to be slow unless the community experiences a severe flood or earthquake. If it is deemed desirable to protect individuals with insurance before the next disaster, then other social institutions may have to step in.

Financial institutions may be able to play a key role in this regard. They could require flood or earthquake coverage as a condition for a new mortgage on residential property just as they now require fire insurance. Over time, an increasing proportion of homeowners will be protected against the financial consequences of a flood or earthquake, thus reducing pressure for providing liberal disaster relief when future floods and earthquakes occur.

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Societal Response to Natural Hazards: Discussion

QUESTION: I would like to ask Dr. Haas how closely they are monitoring the faults.

DR. HAAS: Referring to the Palmdale Bulge, we are not monitoring it directly. There is not an official prediction. If and when there is an official prediction, we will attempt to monitor it very closely, but at present, as far as I know, there is no monitoring going on yet, other than an occasional look by reporters and some of Ralph Turner's clients at the response of some families. But, if it becomes an official prediction, I think it is safe to say that there will be some close monitoring, both of families and of business and governmental actions.

QUESTION: Is there a relationship to possible failures of that size? Have you done any controls for insurance groups that have identified target populations and go out and explain to those people the risk, in contrast to insurance groups that just make the insurance available generally?

DR. ROSSI: We ourselves have not done very much with respect to separating out the two groups. We did ask in our field survey whether the individual contacted the insurance agent or whether the agent had contacted him. We were quite surprised to find that in almost all cases, about 90 percent of the contacts were initiated by the consumer rather than by the agent. I believe that this is a very important aspect of the whole problem on the marketing side.

QUESTION: If you did identify that hazard of supply failure, then possibly one of the policy recommendations would be a more active insurance policy orientation in those areas of high risk.

DR. KUNREUTHER: There is no doubt about the fact that the insurance agent can play a more critical role in the process. We would still consider that to be a failure on the demand side in the sense that traditional theory has always argued that the consumer should initiate the process and be concerned about the risk and the possible losses. I do agree with you, though, that a critical aspect is the insurance agent and the marketing.

DR. ROSSI: Since Howard collected his data, both in North Carolina after the psychic made the prediction in January, and in April in Los Angeles after the Whitcomb hypothesis was broadcast, a number of the major insurance companies refused to sell any additional earthquake insurance. I can give you names, but I won't.

Furthermore, in the last month, one of the major insurance carriers in this country systematically started cancelling its earthquake insurance coverage for homeowners in the Los Angeles area. I have a copy of the letter which was sent to one of the homeowners who just happened to be the head of the building safety department for the city of Los Angeles.

DR. KUNREUTHER: I think one of the reasons the insurance industry is concerned about that aspect of the problem is that the minute an individual perceives the loss to be sufficiently large, he will go out and demand coverage which is very consistent with the kind of results that we had coming out in our field survey. Then they do initiate the process. In North Carolina, there was a substantial demand for coverage afterward, which is why the insurance industry was concerned about continuing to market its policies, so I think it is a very interesting aspect with respect to the two projects.

QUESTION: Have you made an analysis of what will be the future predictions of such disasters if the event should not occur?

DR. ROSSI: No, we have not done such an analysis. We have our hands full with what we are working on now. I think that is a very important consideration and ought to be done.

QUESTION: You mentioned, Dr. Haas, that at the beginning of the two year period, investment declines and savings accrue. Now, I interpreted from that that you meant that as people started putting money into their savings account, individuals would stop spending. Spending in real estate declined. My question is, did you run across what those savings that were accruing were being used for during the two-year period if, for example, they weren't being directed to local investment?

DR. HAAS: Only in a very selective manner. The local savings and loans and banks indicate clearly that they are going to thin out their investments. From the public image point of view they feel they can't entirely stop investments in that area, but they will thin out their investments and put much larger proportions of their investments outside of the target area.

QUESTION: So that would be regional. It would go toward more of a regional level of development.

DR. HAAS: Well, it could go in any variety of other ways. We didn't pursue precisely what other kinds of investments except their geographic focus.

QUESTION: And none of that would include relocation of any of the threatened properties or investments?

DR. HAAS: No, not relocation of properties. Some strengthening of properties clearly is going to take place and some capital will be required for that, but not relocation of structures per se.

QUESTION Did you look at the last-minute reactions? You looked at the last two weeks or whatever. Did you foresee and do people foresee things like jamming of airports, roads, that type of problem occurring? You said that, in the last two weeks, half of the people are going to try to leave temporarily. What is the impact of that?

DR. HAAS: We had it listed under the last two months, actually. It varies a great deal from people leaving two or three months ahead of time to people waiting the last week. No, we have seen no evidence that would indicate there is going to be jamming of highways or any real problems of panic or flight of convergence to speak of. The time period is important in helping people to get adjusted to the concept. There is repeated coverage in the news media. If you have two years to get adjusted to an idea, you can take many actions, and people apparently will take many of their actions well in advance of the last week or two. By the way, one of the most important things that kept coming out was that despite the fact that people would believe predictions as a result of the high scientific consensus, many would still have reservations on the cautious side, saying, well, it may be bigger than they expect and it may come earlier than they expect and, therefore, I am going to take actions accordingly.

QUESTION: It seems to me that the main purpose of this program is to try to persuade the committee to have land use planning so that people will move up from predicted hazard areas. While your research project does not address this problem of why land use planning is not enforced, it seems to me that this is the main problem.

DR. HAAS: No, I think that we have addressed that issue, very definitely, in terms of the field survey. We did try to get an understanding as to what the public's knowledge was on alternative hazard mitigation measures. Surprisingly, we found that people have limited knowledge about what can be done by themselves or what has been done by the federal government with respect to land use regulations.

I should emphasize, however, that our study was essentially directed toward homeowners living in flood and earthquake-prone areas and was not so much studying community officials who would be concerned with land use regulations. The conclusions, however, do directly follow. I think one is going to have to think about insurance as one of a set of adjustments that can be used in conjunction with land use regulation and hazard mitigation. So, in that sense, we are very concerned about how the two of them dovetail.

QUESTION: The implications of Dr. Haas's findings about the unavailability of insurance after the warning have to be interpreted with an understanding of what insurance is as a private sector activity and in relation to disaster relief.

DR. HAAS: Let me comment that if I were an insurance executive, I would behave very much like the current insurance executives are behaving, and that is why the issue needs to be faced now. What kind of functional substitute should we have as a society for the communities after a credible prediction? Indeed, it is not going to be feasible for an insurance company to continue to offer any Johnny-come-lately as much earthquake coverage as he wants. We ought to start thinking seriously about the alternatives to that because that seems to be the key to a great deal that happens to the local economy and to the social disruption that follows.

DR. KUNREUTHER: However, to add one point, the damage to many of the homes that would suffer an earthquake may not be nearly as severe as perhaps one would expect before the fact. We were very surprised from our survey that people did expect a large amount of damage from a severe earthquake and therefore insurance would become an attractive option from their point of view.

However, if it is a wood frame house, it might be possible for the insurance industry to find that with their five percent deductible they would not suffer as severe a loss as perhaps they had anticipated. I think it is an open question that has to be looked at in more detail in future work.

4

MUNICIPAL WASTE AS A RESOURCE

Municipal Waste as a Resource

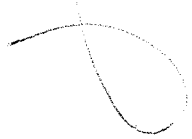
Research studies of municipal waste as a resource examine the applicability of selected technologies for solving this environmental management problem.

RANN researchers view the problem of municipal waste as one requiring solutions that are economically feasible, environmentally sound, and practicable with minimal energy consumption (Korbitz). One RANN-sponsored project assesses the role of soil invertebrates in stabilizing water treatment sludges placed on agricultural land (Hartenstein). Subsurface injection is one of the more economical and technically superior methods of land application of liquid residuals from municipal waste treatment plants (Smith). Disinfection of municipal sludge by high energy electrons continues to be studied at the Deer Island Wastewater Treatment Plant in the Boston area (Trump).

Two roundtables continued to explore the issue of municipal waste as a resource. The validation of evapotranspiration as an alternative for treating household wastes in areas having high water tables or soils that do not percolate well is being tested in seven states (Pusey).

The entire virus-inactivating effectiveness of high-energy electron treatment of effluents and liquid sludge is being studied at the Boston Waste Treatment Plant on Deer Island in coordination with an MIT study of the biochemical and economic feasibility of such treatments (Metcalf). Two investigators reported on a modified technique which employed bentonite to monitor indigenous enteric virus levels within contact stabilization activated sludge treatment plant (Moore, Sagik).

Panel Papers



Municipal Waste as a Resource

William E. Korbitz
Manager, Metropolitan Denver (Colorado) Sewage Disposal District Number 1

The residue from wastewater treatment plants must be used beneficially in a manner that is environmentally sound and economical, with a minimum of energy consumption. The best present use of such residue is as a soil conditioner for agricultural purposes, and it is important that research establish the safety of such use as well as develop alternative methods of such use. The three research projects to be discussed in this session include two dealing with the stability and safety of wastewater sludge; the third describes the application of liquid sludge to land with subsurface injection.

The disposal and recycling of the wastes from our society presently constitute a national problem of major proportion. This is true of both solid wastes and liquid wastes.

The solid waste, or garbage and trash disposal problems have faced local government officials for many years, and we must take a good look at every possible means of disposal, or preferably, recycling of those solid wastes.

The liquid waste problem results from ever increasing levels of treatment of wastewaters or sewage. As treatment levels increase, the quantities of residue or sludge increase markedly. The disposal or recycling of this sludge, more than 20,000 dry tons per day, more than 140,000,000 gallons per day, requires a high priority of attention by officials at all levels of government and a high priority for research funding.

Two major areas of concern and research needs are the methods of disposing or recycling of sludge and the safety of health and environment for various methods of disposing or recycling of sludge.

After years of disposing of much of the nation's sludge by incineration and ocean dispersal, it now appears that the primary method of sludge disposal or recycling is on and in the land. For many decades in this country and for centuries in other countries, sludge has been used as a soil conditioner and fertilizer with much benefit and few, if any, problems for health and environment. We are more concerned about health impacts now, however, so it is essential that we develop sludge processing and recycling methods which provide the ultimate in health and environmental safety.

There are three sludge recycling research projects sponsored by the NSF. One project is determining the ability of soil invertebrates, worms and such, to stabilize sludge. A second project is investigating the use of high energy electron irradiation for disinfecting and sterilizing sludge. A third project is demonstrating the feasibility of subsurface injection of sludge, making the sludge readily available in the root zone of crops.

The results of research projects such as these three will have a major impact on our society inasmuch as roughly 50 percent of the cost of wastewater treatment is due to processing and disposal or recycling of sludge. The estimated national cost of sludge processing and disposal or recycling is $2,000,000 per day, more than $700 million per year. So in addition to providing agricultural benefits with the residue of wastewater treatment, we can also drastically reduce wastewater treatment costs for our citizens.

The Use of Soil Invertebrates in Sludge Stabilization

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State University of New York, College of Environmental Science and Forestry, Syracuse, New York

A 1972 congressional amendment of the Water Pollution Control Act has resulted in an increasing accumulation of sludges at wastewater treatment plants throughout the country. Notwithstanding the current problems of pathogenicity, offensive odors, and contamination by heavy metals, sludges constitute a potential wealth of plant nutrients and humus. These resources can be realized only through appropriate research and biological management. Certain soil invertebrates can be employed to accelerate the decomposition of putrefactive and fermentative substances and to humify sludge into potentially fertile, stable, organic soils. Data from this research are providing background information on the potential use of invertebrates as vectors of microorganisms that can increase the nitrogen content of sludges, decrease the nitrate level, and convert sulfides into more useful nonodorous sulfates.

Sludge is a semi-liquid suspension of solid matter which is formed in wastewater treatment plants from household and industrial sewage. Sludge poses the problems of pathogens, toxic heavy metals, and an excess of certain types of organic matter, which, under adverse conditions, can give rise to fermentative and putrefactive odorous substances.

At present, approximately five million tons of dry sludge are produced annually in our country. Sludge can never be truly disposed of; it can only be managed. The best form of management would entail a reduction in the volume of sludge and an improvement of its quality. This type of management should also involve a minimum amount of handling and costs.

Three managerial practices are presently in use. The first, incineration, is largely on its way out because it produces air pollution; because of the need to dispose of its ash residue, and because of the large quantities of energy it consumes.

The second practice, ocean dumping, is used to eliminate about eight percent of the nation's solid sludge material. This practice also is costly and causes pollution.

In the third practice, sludge is disposed of in landfills or is used to increase or restore soil fertility in agriculture and strip-mine reclamation.

It can be argued that sludge is a valuable natural product. On the average it contains three percent nitrogen (N), 2.5 percent phorphorus (P), and 0.5 percent potassium (K). These values may be compared to what is present in fertile mineral soils: 0.02 to 0.25% N, 0.02 to 0.5% P, and 0.05 to 3.5% K. In converting the percentages of sludge NPK into weights, we obtain 150,000 tons of nitrogen, 125,000 tons of phosphorus, and 25,000 tons of potassium (based on the current national annual production of five million tons of dry sludge). Based on present agricultural needs, these nutrients could provide about two to three percent of our main fertilizer requirements. Sludges also contain desirable amounts of other essential plan nutrients, such as magnesium, calcium, sulfur, and molybdenum.

THE NEED FOR RESEARCH ON SOIL INVERTEBRATES

The organic matter in sludge is rich in humus and similar to soil in certain respects. Two major differences, however, are the types and excessive amounts of organic matter in sludges, compared to mineral soils. In general, a

*Presenter

rich, fertile mineral soil contains about 3 percent to six percent stable organic matter. In contrast, sludges usually contain from 30 to 60 percent organic matter, some quantities of which are highly unstable and noxious. If it were possible to reduce the organic matter in sludges by 90 percent and alter its form, the total mass of sludge would be reduced by about 25 to 50 percent, and its quality would be enhanced. A more desirable objective would be to reduce the organic matter content minimally, but to convert it into a stable humus which would be very beneficial to farmers, gardeners, and the like.

Is it possible to do this without destroying the biological value of sludge as a potential contribution to the soil ecosystem? Is it possible to do this in an economical way?

We believe soil invertebrates can be used effectively to convert a relatively infertile sludge into a fertile, organic topsoil. We view the soil system, with its biological and physical components, as being well-adapted for the utilization of organic input of various forms. These forms vary from leaf litter to wood to the carcasses of animals. All of these materials have quite different biochemical properties, but each type can be readily degraded to stable organic fractions in the soil. This contrasts with aquatic systems, where the past practice of adding high levels of organic nutrients has generally brought forth adverse effects.

In a proposal to RANN, we stated that earthworms, millipedes, slugs, and sowbugs are dominant large invertebrates whose role in nature is to feed on rotten wood, which is rich in fungi, bacteria, and protozoans. The invertebrates, in conjunction with soil microorganisms, help immensely in producing humus, and in improving the physical and chemical properties of soils.

SOME QUESTIONS IN NEED OF ANSWERS

In our RANN project, we are attempting to answer the following questions:

- To what extent will the organic content of sludge be reduced in quantity upon passing through the gut of certain soil invertebrates, notably earthworms and sowbugs?
- How important and active are these invertebrates in turning over sludge?
- Can they establish conditions to facilitate microorganisms in their sludge-digestion activities?
- Will sludge itself, in view of interactions that occur between the invertebrates and microorganisms, become rich in enzymes whose main action is to humify organic matter?
- Will there be an increase in cation exchange capacity as sludges are converted into soils? That is, can invertebrates increase the capacity of the material to buffer soil pH and to store certain important plant nutrients, such as potassium and calcium?
- Can certain soil invertebrates add nitrogen to sludge through the process of nitrogen fixation?
- Can earthworms and sowbugs inactivate human pathogenic bacteria?

RESULTS OF RESEARCH

Only five months have passed since we first received RANN support, but it is already possible to provide answers to some of the questions, and to describe some experiments we are planning for the future.

Four kinds of sludges, from four separate treatment plants, are being studied. Three of these were obtained from anaerobic digesters and one from an aerobic digester. The anaerobic digests from two of the plants were toxic to earthworms, which thus precluded their feeding. Percol 738, which was added as a thickener to one of these sludges, was ruled out as a cause of toxicity. Sulfide and anaerobicity are being investigated at present.

The aging of sludge appears to be an important factor in the suitability of sludge for certain kinds of biological activity, since the two toxic sludges became amenable to feeding one month after being removed from the digesters. The beneficial effect of aging has also been observed in glasshouse plot experiments where the four different sludges were applied to the surface of topsoil. Under controlled conditions, we found that, although the density and diversity of soil invertebrates were initially low in the toxic sludges, they increased rapidly during one month of aging and became similar to the density and diversity of soil invertebrates in the nontoxic sludges.

We now turn to the questions raised earlier. To answer the first question regarding the decomposability of organic matter in sludge, it was necessary to establish sound analytical procedures for measuring the differences between various components of organic matter in the sludges. We have succeeded in characterizing the four types of sludges in terms of their carbohydrate, protein, huminoid, lignoid, and mineral content, though we have not yet examined the effect of invertebrate feeding on these components. Two observations, however, are worthy of comment. First, the carbohydrate content in the sludges was quite high (three to 11 percent) compared to what is normally present in soils (about 1 percent). The organic nitrogen content was higher also. Future monitoring of these nutrients may be used as a means of determining the stability of a sludge. Second, the aerobic sludge had three to five times as much huminoid material and three to ten times as much organic nitrogen as the anaerobic sludges. This finding very likely relates to the rock-like consistency taken on by the aerobic, but not the anaerobic sludges, upon drying. This observation suggests the need to know more about the relation of the chemistry of sludges to their physical properties and the effect of these properties on soil organisms.

With respect to the second question, the feeding and turnover of sludge, we have learned the following: (1) The fresh aerobic digest was vastly superior to the fresh anaerobic digests as a food substance, independent of pH and heavy metal content. Approximately four times as much of the aerobic sludge was consumed, per unit time and unit weight of earthworm or sowbug, in comparison to the most preferred of the anaerobic sludges. In time, however, following aging of the sludges under aerobic conditions, one of the anaerobic digests was consumed to a greater extent than either the fresh or aged aerobic digest. (2) The earthworm can consume and eliminate

more than its own weight of the aerobic sludge in a period of one day. (3) The sludges were consumed maximally by sowbugs at around 20°C, while below a critical moisture level, consumption ceased. We are presently investigating sludge consumption by earthworms and sowbugs as a function of temperature, moisture, and composition.

The answer to our third question is that sludge will necessarily stabilize at a very low rate, in the absence versus presence of soil invertebrates, since there will be little exposed surface area on which the microorganisms can carry out oxygen-requiring degradative work. An assessment of this question was carried out by comparing the rate of oxygen consumption of uneaten sludge to that of sludge fecal pellets. A unit weight of such pellets from sowbugs or earthworms consumes oxygen two to five times more rapidly than a unit weight of sludge itself. This means that a far greater number of bacteria and other microorganisms can proliferate and become active in the process of further stabilizing sludge after it has passed through the animals' gut. It also means that the organic matter in sludges can be reduced two or more times more rapidly in the presence rather than absence of invertebrate decomposer organisms.

An answer to our fourth question, relating to an increase in humifying enzymes, requires some preliminary comment on humifications. Soil biologists generally agree that the most stable organic matter in soil is the heterogeneous group of substances that were mentioned above as huminoids and lignoids; collectively, these may be termed humus. In contrast, there are many reactive or less stable organic substances in soil, such as carbohydrates and proteins. Humus is produced from carbohydrates, proteins, and a host of other materials, including certain substances that are derived from the ligneous skeletal material of wood. This process is so complex, however, that little is known about it. Nevertheless, a number of enzymes are known to be involved.

We have completed an examination of these enzymes in earthworms, sowbugs, millipedes, and slugs, and in certain microorganisms that live within these invertebrates. For now we can say that all of these invertebrates are able to break down cellulose, but none are able to degrade lignin. In addition, the invertebrates contain enzymes that are involved in humification. They also contain microorganisms that are able to degrade various building blocks that are derived from lignin. Part of our research effort is an elucidation of the separate enzymological roles of microorganisms and invertebrates in the production of humus.

The fifth question, regarding an alteration in cation exchange capacity, is being investigated at present. We expect to find, in view of what is known of the role of earthworms in soils, an increase in this parameter as the sludge becomes stabilized through the interactions of the microbes and invertebrates. A contrary finding, however, is possible.

The sixth question, concerning the ability of these invertebrates to add nitrogen to the soil, can be answered negatively. This question was raised because other investigators have shown that certain invertebrates are able, through gut bacteria, to convert atmospheric nitrogen into ammonia. In our work to date we were unable to detect nitrogen fixation in all of the animals studied under a wide variety of circumstances.

The last question deals with pathogenic bacteria such as *Salmonella*. All of the invertebrates we have examined are able to live in media which contain more than a million times more *Salmonella* than one would usually find in sludges. We are presently investigating whether the invertebrates are able to destroy these pathogens.

HOW KNOWLEDGE FROM THE PROJECT CAN BE USED

Having stated what we have been doing so far, we should discuss the direction into which our research is presently going.

First, we foresee the practical use of earthworms in accelerating the stabilization of sludges. To this end we are beginning to culture three different species, each of which has different biological characteristics. We cannot predict which species will be most useful and beneficial, but we can make some general helpful statements: (1) Although different species of earthworms achieve sexual maturity at different ages, and though each species has its own characteristic fertility rate, some range approximations can be advanced for earthworms as a whole in calculating the feasibility of using these animals to produce topsoil from sludges. In general, earthworm species produce from about ten to 50 cocoons per year, with from one to 20 eggs per cocoon, of which a variable number will hatch. Sexual maturity is reached in about 20 to 70 weeks. Earthworm culturists claim it is possible to produce up to 50,000 breeding worms from 250 cocoons annually. A culture bed eight feet by four feet by one foot deep will support 150,000 worms. (2) An acre of fertile soil contains about 0.5 to 1.0 ton of earthworms (wet weight); under proper artificial culture conditions this range can be increased about 300-fold. (3) A ton of earthworms can turn over a ton of soil per day; 300 tons of earthworms may be able to turn over about 100 to 300 tons of culture medium (sludge) per day, assuming conditions are ideal. In metropolitan areas the size of cities like Albany, New York, and even in large cities like Chicago and Los Angeles, assuming the wastewater treatment plants contain a sufficient amount of dumping area, the use of earthworms for converting sludges into valuable topsoil can become a reality.

Second, we will be examining the possibility of using earthworms as vectors of nitrogen-fixing bacteria, nitrate-reducing bacteria, and sulfur bacteria, depending on the requirements of the sludge. If a sludge is deficient in nitrogen, nitrogen-fixing bacteria may convert atmospheric nitrogen into ammonia which can be incorporated into the sludge. If a sludge is overly rich in nitrate, nitrate-reducing bacteria may convert the nitrate to ammonia or nitrogen gas. If there is an excess of sulfide, one of the chief causes of foul odors, sulfur bacteria may oxidize the sulfide to sulfate, an important plant nutrient.

Third, since earthworms may be useful and helpful in stabilizing sludges, more information must be obtained regarding the toxicological properties of sludges. Next year we will be examining a variety of aerobic and

anaerobic digests from various wastewater treatment plants. Those sludges which prove to be toxic will be subject to chemical and biological analyses designed to determine the identity of the toxicological agents.

Fourth, much more information must be obtained on the production of cation exchange capacity and elimination of offensive odors in sludges. We must learn what the potential is in earthworms and microorganisms for converting labile organic materials into stable humic substances under field conditions. We must also determine under what conditions sludges are most amenable to soil humification.

Finally, we will examine the invasion of organisms from soil to land-applied sludge. The type and numbers of invertebrates which enter this sludge will serve as an index of sludge stabilization and its potential for further use. An assessment of the invasion rates and community structure under different application procedures will be used for developing optimum management schemes for sludge utilization.

Land Management of Subsurface-Injected Wastewater Liquid Residuals

James L. Smith Associate Professor, Colorado State University

Subsurface injection provides a technically superior and more economical method of applying liquid residuals from municipal treatment plants to land than alternative methods. Shallow soil injection equipment is being evaluated at various locations in the United States to determine relative economy, aesthetic and sanitary acceptability, and energy requirements.

Close coupling of the research with representative users has been an integral part of the project. This has provided a realistic assessment of its acceptability and a basis for comprehensive environmental impact analysis.

Subsurface injection appears to provide a technically superior and more economical method for land application of liquid residuals (sludge) from municipal treatment plants than alternative methods. Shallow soil injection equipment is being evaluated at Boulder, Colorado, and other locations to determine the relative economy, aesthetic and sanitary acceptability, and energy requirements.

The research is closely coupled with representative users. This has provided a realistic assessment of its acceptability and a comprehensive environmental impact analysis. Apparent major advantages of the system include high capacity and low costs, adaptability to a variety of needs, and elimination of odors, insects, and runoff pollution. Perhaps the most significant advantage is that the sludge is handled in such a way that it is seldom, if ever, visible.

INJECTION SYSTEM DESIGN AND OPERATION

The injector sweep shown in Figure 1 consists of a spring-loaded chisel plow shank with a wide high-lift cultivator sweep and a steel flow divider mounted behind the sweep. As the sweep passes through the soil, it creates a broad, shallow cavity into which the sludge is injected. Soil falls over the wings of the sweep, filling the cavity, mixing with the sludge, and filling the vertical slot formed by the shank. Normally, sludge is injected at a depth of four to six inches, providing an aerated environment for the sludge and ensuring rapid drying.

FIGURE 1—Injector Sweep and Flow Divider

The flow divider discharges the injected material under the wings of the sweep and not directly behind the shank. This provides uniform coverage and mixes the injected material with soil. The size and shape of the flow divider can be changed, depending on the consistency of the material to be injected. A modified sweep and deflector are also available for use in shallow frozen ground.

The operational subsurface injection system is shown in Figure 2. This system has seven injector sweeps of the type previously described. Sludge is supplied to the injector at approximately 700 gpm through a 4 ⅛-inch, 660-foot flexible hose which is attached to and pulled by the injector. Several methods can be used to supply sludge to the hose, depending upon the particular installation. Use of the flexible hose allows continuous injection of large volumes of sludge from storage facilities. It thus increases operating efficiency and, as a secondary benefit, aids operation in adverse weather.

Most of the injectors have been mounted on John Deere[1] Model 350 crawler tractors. The crawler can be equipped with 33-inch wide tracks to provide maximum flotation and thus it can operate in extremely adverse conditions. Repeated passes can also be made at shorter intervals, frequently on a daily basis. At Boulder, Colorado, the injector has been used during both rain and snow storms and with over 12 inches of snow on the ground. General specifications for the injector are shown in Table 1. Additional details of the injector system design and operation are given by Smith and Houck (1976).

MONITORING LAND APPLICATION SITES

The concept of mass balance has been used for predicting groundwater quality and buildup of heavy metals in soils due to application of wastewater sludges (Smith et al., 1976). The concept is based on the principle of continuity of mass and an idealization of the flow system. Data from the Boulder, Colorado, municipal sludge application site are used to illustrate the practical application of the concept.

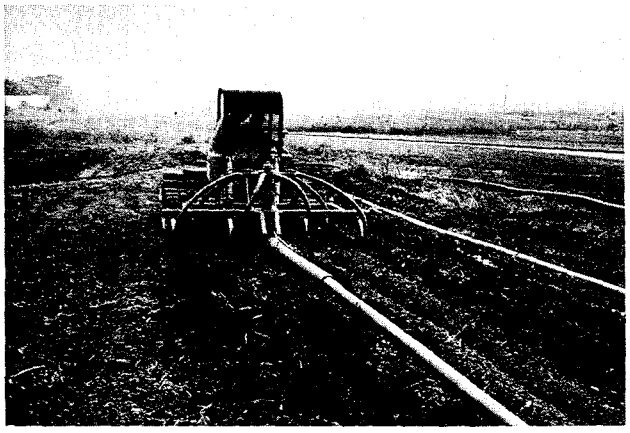

FIGURE 2—Subsurface Injection System

[1]No statement in this paper, written or implied, pertaining to brand names constitutes endorsement of the product by Colorado State University and/or the National Science Foundation.

Table 1—Specifications for Seven-Sweep Injector

Operating speed	0.5 to 1.5 mph
Capacity per sweep	60 to 120 gpm
Operating depth	3 to 12 inches
Tractor power required	
Wheel type	100hp
Crawler type	42 hp
Field capacity	20,000 to 80,000 gal/acre
Pressure required at hose inlet	30 psi
Maximum solids content	8%
Operating efficiency	95%
Area covered per hose attachment	18 acres

Mass balance reduces the lag time between application and measurement and uses measurements made prior to dilution of potential contaminants. A major deficiency in the concept is that, while it predicts a buildup of heavy metals in the soil, it does not indicate their availability to plants. However, other research has indicated there is no cumulative effect of heavy metals and plant uptake is not normally a problem in soils having near neutral pH (Kirkham, 1975; Lue-Hing, 1975; Trout et al., 1976).

The effect of applying wastewater residuals was evaluated using soil, leachate and groundwater samples (Trout et al., 1975). Sludge samples were taken on a monthly basis. Generally, plant nutrients were determined on a monthly basis and heavy metals were determined every three months.

Average experimental data for heavy metals is shown in Table 2. None of the increases or decreases in groundwater concentration are regarded as being statistically significant.

Assuming the flow rate of groundwater in a finite depth aquifer is much larger than the flow rate of leachate from an application site, the well-mixed concentration of potential contaminants will approach (Smith et al., 1976):

$$C_g = \frac{Q_L}{Q_i}(C_L - C_o) + C_o$$

Where: C_g = groundwater concentration after complete mixing
C_o = background concentration of groundwater
C_L = leachate concentration
Q_i = rate of flow of groundwater
Q_L = rate of flow of leachate

In the case of nitrate, it was predicted that the concentration of nitrate in the groundwater flowing under the Boulder site would be increased by 6 mg/l during a period when sludge was applied at regular intervals. This value compared favorably with nitrate concentrations measured in samples taken over a six-month interval from wells located near a groundwater flow line. No other potential contaminants from sludge could be traced in the groundwater.

Using the above equation and data obtained from leachate samples, it is possible to predict whether or not C_g will differ sufficiently from C_o to be detected with

Table 2—Analysis of Sludge, Leachate, and Groundwater for Boulder Site

Element	Sludge (ppm[1], 4.3% solids)	Groundwater Initial (mg/l)	Groundwater Affected (mg/l)	Leachate (mg/l)
Ag	60	0.0001	0.0001	0.0005
Cd	8.6	0.001	0.0016	0.007
Cr	639	0.0025	0.0025	0.004
Cu	820	0.0011	0.009	0.10
Fe	0.87%	0.05	0.051	0.07
Hg	3.2	0.0002	0.0005	0.0005
Mn	162	0.53	0.57	0.04
Ni	21	0.03	0.03	0.05
Pb	768	0.0031	0.0035	0.008
Zn	1,110	0.007	0.041	0.54
B	73	0.48	0.25	
Ca	2.3%	100	103	
Cl	729	133	102	
K	0.12%			
Total N	3.3%	4	4	
NH_4-N	1.3%	0.42	0.36	
Total P	4.7			
PO_4-P		2	4	

[1] Unless otherwise indicated.

confidence. If not, there is little to be gained by using monitoring wells.

The buildup of heavy metals in the soil can be estimated by subtracting quantities removed with leachate from quantities applied in the sludge. For a plot at the Boulder site, no significant correlation could be established with values measured in soil samples (Smith et al., 1976).

Buildup of plant nutrients can also be estimated using mass balance. However, the problem is complicated by the need to estimate many of the values required for the analysis. This is particularly true in the case of nitrogen. In general, it is recommended that plant nutrients retained in the soil be determined by analysis of samples. This procedure has been used satisfactorily at the Boulder site.

ECONOMIC ANALYSIS

Costs for sludge stabilization with ultimate disposal on land by continuous subsurface injection were analyzed for the three representative treatment systems shown schematically in Figure 3. To account for possible economics of scale, the analysis was expanded to include 3, 10, and 30 mgd plant sizes for each treatment system. Also, because of the uncertainty associated with an assumed economic return from sludge-treated lands, the analysis was completed with and without a crop return. Costs associated with sludges were separated into three categories: (1) costs for in-plant sludge stabilization, (2) costs for transporting sludge from the plant to the application site, and (3) costs for land application by subsurface injection.

The sludge stabilization processes were designed using typical influent wastewater characteristics and process performance specifications. Details of these assumptions and the methods of analysis are given by Smith and Houck (1976).

Relative costs associated with in-plant sludge stabilization, transportation, and subsurface injection are shown in Tables 3 and 4. Table 3 shows costs with return from land, and Table 4 shows costs without return from land.

Results of the economic analysis indicate that the cost of producing stabilized sludge is strongly influenced by the wastewater treatment process design. Alternative I, which produced the most sludge, had the least cost for stabilization. Since stabilization costs were a major portion of the total annual sludge costs, the slightly larger land areas and greater injection system costs required for the larger volumes of sludge were more than offset by the lower stabilization costs. This resulted in the least total annual sludge costs for all plant sizes of Alternative I.

Stabilization represents approximately 50 percent of total annual sludge costs. If the number of processes and/or degree of treatment could be reduced, sludge stabilization costs could be decreased. Subsurface injection eliminates odor and reduces runoff pollution problems associated with most other land application systems. Although further research is necessary, it may be possible to utilize subsurface injection with less stabilized sludges and thereby reduce total sludge costs.

Transportation costs may be a significant portion of the total sludge costs in small treatment plants. Regardless of the transportation system used, the required initial

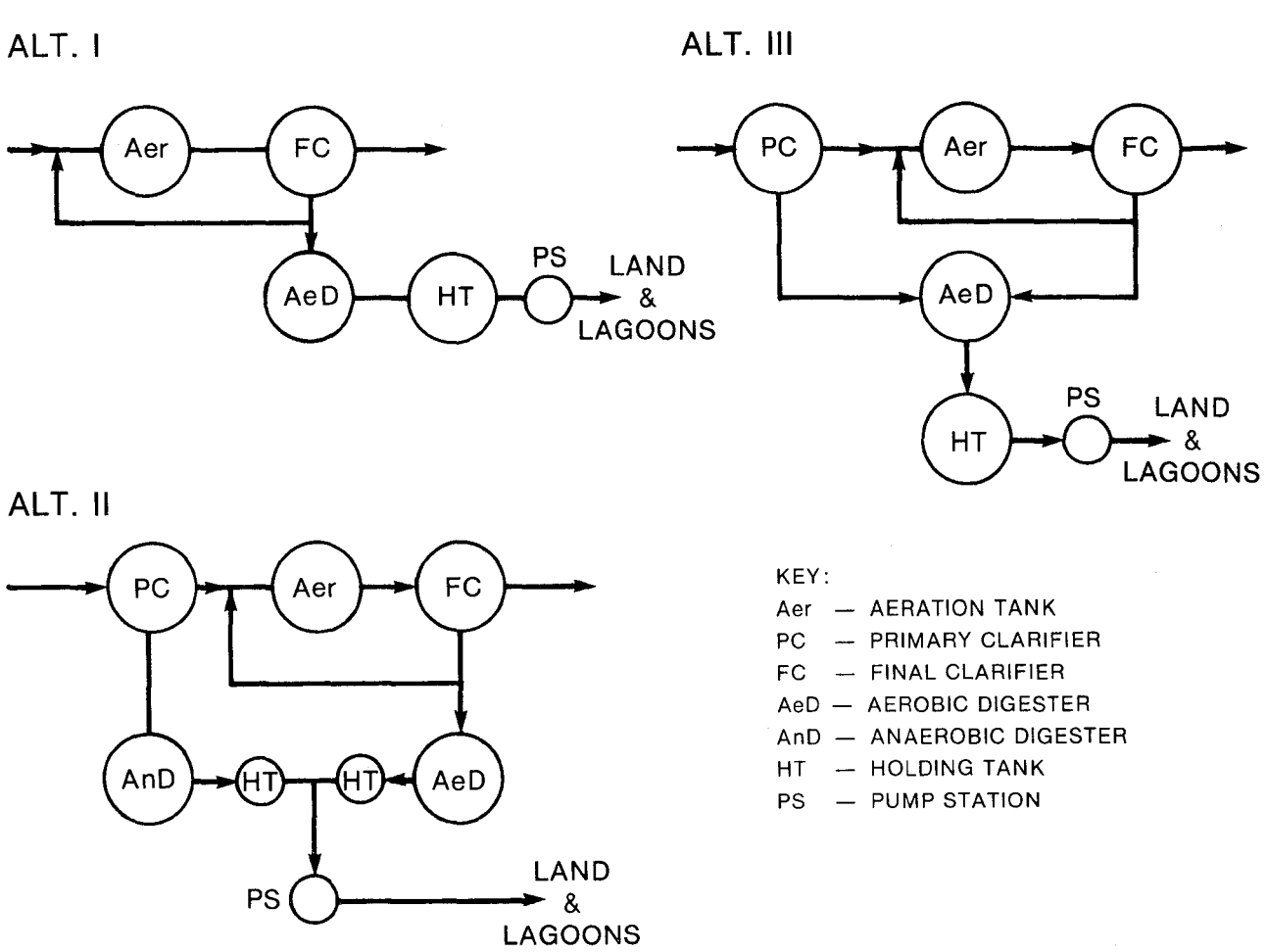

FIGURE 3—Treatment Systems Considered in Economic Analysis

investment is nearly the same for plant sizes up to approximately 10 mgd. Also, it is relatively insensitive to the quantity of sludge produced by different treatment systems. Transportation operating costs, while proportional to the amount of sludge produced, are not significant until the plant size approaches 30 mgd. The transportation distance is more important since it affects both capital and operating costs.

Major factors affecting injection systems costs are the cost of land and land preparation. Cost of the actual injection system hardware is minor and relatively insensitive to the quantity of sludge produced. Because land area requirements and injection system operating costs are directly related to the quantity of sludge produced, in-plant facilities and system design deserve serious attention.

Table 3—Sludge Stabilization, Transportation, and Injection Costs with Return from Land

		Equivalent Annual Cost					
Alternative	Plant Size (mgd)	Dry Solids (T/yr)	Stabilization ($1,000)	Transportation ($1,000)	Injection ($1,000)	Total ($1,000)	Total Cost per Ton of Dry Solids ($/ton)
I	3	840	69	76	17	162	192
	10	2,800	160	98	40	298	107
	30	8,400	370	160	110	640	76
II	3	750	90	83	15	188	250
	10	2,500	180	100	36	316	129
	30	7,500	430	180	94	704	94
III	3	820	98	80	17	195	239
	10	2,700	220	110	40	370	135
	30	8,200	540	180	110	830	101

Table 4—Sludge Stabilization, Transportation, and Injection Costs Without Return from Land

Alternative	Plant Size (mgd)	Dry Solids T(/yr)	Equivalent Annual Cost: Stabilization ($1,000)	Transportation ($1,000)	Injection ($1,000)	Total ($1,000)	Total Cost per Ton of Dry Solids ($/ton)
I	3	840	69	76	21	166	197
	10	2,800	160	98	54	312	112
	30	8,400	370	160	150	680	81
II	3	750	90	83	19	192	255
	10	2,500	180	100	48	328	134
	30	7,500	430	180	130	740	98
III	3	820	98	80	21	199	244
	10	2,700	220	110	54	384	140
	30	8,200	540	180	150	870	106

Potential agricultural returns from sludge-treated lands are relatively minor compared to total annual sludge costs. Returns for the 3 mgd plants were $4,000 or approximately 2 percent of the total annual sludge costs. For 30 mgd plants, the returns were approximately 6 percent of the total annual sludge costs. However, in the latter case, this was a return of approximately $40,000 which may be important in the total system economics. Agricultural cropping should be considered for site management, particularly nitrogen, and not necessarily for economic return.

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Disinfection of Municipal Sludge by High Energy Electrons

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A. J. Sinskey
E. W. Merrill
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D. N. Shah

The technical and economic feasibility of disinfecting municipal sludges for agricultural use by treatment with high energy electrons is being evaluated at the Deer Island Wastewater Treatment Plant of the Metropolitan District Commission (Boston).

The radiation source is a high voltage 50 kilowatt electron accelerator arranged in a shielded enclosure to deliver controllable doses to 100,000 GPD as the material flows through in a wide, thin stream. Bacterial and viral disinfection, parasitic deinfestation, improvement in sludge dewatering characteristics, and destruction of toxic materials are being studied at high flow rates on raw and digested primary sludges and treated effluent. Modes of application to existing and new wastewater treatment systems and data essential for design, operation, cost and energy use analyses are being determined.

This is a continuation of research in which the influence of dose, dose rate, and oxygen availability were evaluated. These indicated that a dosage of 400,000 rads is adequate for sludge disinfection.

*Presenter

DEER ISLAND ELECTRON RESEARCH FACILITY

Electron disinfection of municipal sludge is directed primarily at the destruction of pathogenic organisms through an injection of an appropriate dosage of high energy electrons. There is evidence that other useful effects—improved dewatering characteristics and breakdown of toxic compounds—are also produced through disinfection. This new approach rests on a long background of research with ionizing radiations such as X-rays, gamma rays from radioactive materials, and high energy electrons. Electrons, a basic particle of nature, appear to us as the most desirable of these.

The technical and economic feasibility of electron disinfection is being evaluated on a full-scale research unit at Boston's largest wastewater treatment plant at Deer Island (Figure 1).[1] This sludge treatment facility was brought into operation in May 1976, toward the end of the second year of NSF/RANN support of the MIT project. It was engineered as an in-line treatment system capable of delivering a disinfecting dosage of 400,000 rads to 100,000 gallons of municipal sludge per day. This is one-third of Deer Island's daily sludge throughput. Deer Island, a primary wastewater treatment plant operated by the Metropolitan District Commission, processes 300 million gallons of influent wastewater per average dry day from Boston and over a score of surrounding communities.

IN-LINE ELECTRON IRRADIATION OF SLUDGE

At the Deer Island research facility, as the sludge passes over the top of a rotating, stainless steel drum, it is ionized throughout its volume by the high energy electron beam which sweeps at high speed back and forth across the full width of the drum. At the irradiation region the sludge layer is 1.2 meters wide and 2 mm thick, moving at the drum surface speed of 2 meters per second. The sludge moves through the scanning electron beam in about one hundredth of a second.

During this brief exposure to the 400,000 rad dose, over 10 trillion energized electrons impinge on each square centimeter of the sludge surface. As they lose energy in collisions with atoms and molecules, the electrons produce ionization which causes powerful disinfecting and detoxifying effects. The absorbed energy from this dosage would raise the temperature of water about 1°C.

In the electron accelerator used at Deer Island, 60-cycle AC power is first transformed into high voltage DC power, and this high voltage is then applied to a vacuum

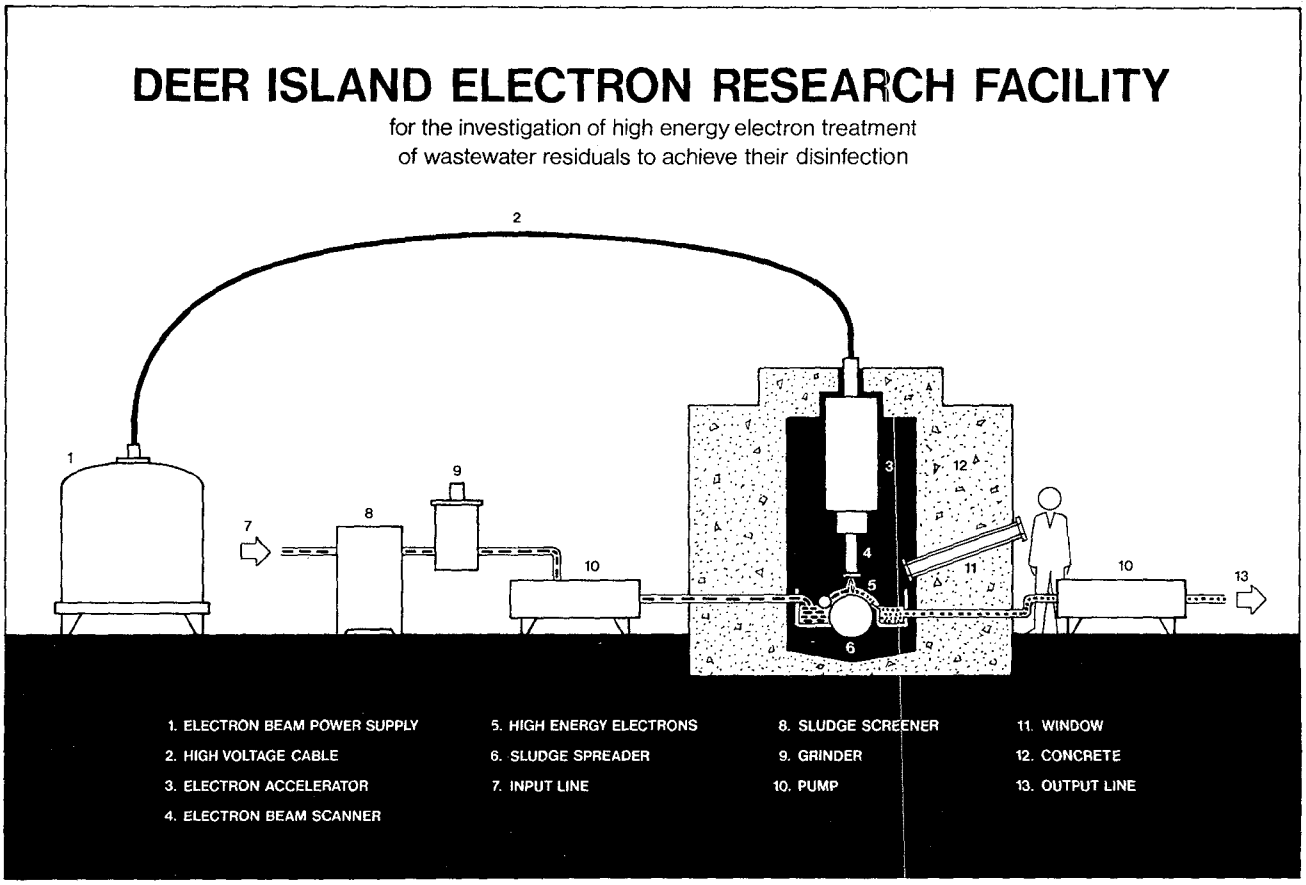

FIGURE 1—Deer Island Electron Research Facility for the Investigation of High Energy Electron Treatment of Wastewater Residuals to Achieve Their Disinfection

tube of special design to accelerate electrons emitted from a hot filament at one end. The electrons accumulate energy as they are forced by the electric field toward the positive electrode at ground potential. Each electron acquires an energy equal to the product of its electronic charge and the applied voltage. The electrons reach and continue into the evacuated scanner system now moving with nearly the speed of light. At this point, by the action of a time-varying magnetic field, they are swept back and forth through an angle to emerge as a fan-shaped beam from vacuum into air through the thin, metal window at the end of the scanner. This rapidly scanning curtain of energized electrons impinges on the full width of the moving band of sludge a short distance beneath (Fig. 2).

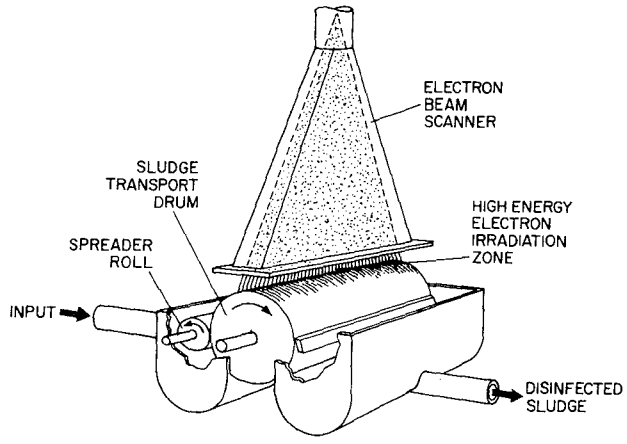

FIGURE 2.

The Deer Island accelerator is supplied on rental to MIT as standard equipment from the High Voltage Engineering Corporation of Burlington, Massachusetts. The voltage which accelerates the electrons is 850,000 volts, the output electron beam power is 50 kilowatts, the conversion efficiency from 60-cycle input electric power to electron beam output power is over 80 percent. This electron accelerator is an extremely powerful source of ionizing energy; it would require 3.5 million curies of radioactive cobalt to emit gamma rays with the equivalent ionizing power.[2]

BACTERIAL DISINFECTION

The disinfection ability of high energy electrons on salmonella, fecal streptococci, and other pathogenic bacteria was confirmed in 1974 at MIT on small quantities of raw and digested Deer Island sludge during the first year of the RANN grant (Fig. 3).[3] This work led to the selection of 400,000 rads as an adequate dosage for the 100,000 GPD Deer Island system. Closely corresponding disinfection is now being obtained in electron-treated sludge treated in the high flow rate system. The delivered

Table 1—Bacteria in Deer Island Raw Sludge, Digested Sludge, and Chlorinated Effluent

	Total Plate Count	Total Coli-forms	Fecal Strepto-cocci
Raw Sludge	2×10^{6}/ml	6×10^{7}/ml	7×10^{4}/ml
Digested Sludge	3×10^{6}/ml	4.4×10^{5}/ml	1×10^{4}/ml
Chlorinated Effluent	3×10^{5}/ml	1.4×10^{3}/ml	1×10^{1}/ml

dosage can be controlled by adjusting the electron beam current.

Table 1 shows the bacterial content per ml in Deer Island raw sludge, digested sludge, and chlorinated effluent in terms of total count, total coliforms, and fecal streptococci. Figure 3 shows the rapid diminution of bacteria in raw primary sludge with electron dosage for total bacterial count, salmonella, and coliforms. Many such studies have confirmed the adequacy of 400,000 rads for bacterial disinfection of municipal sludge.

VIRAL DISINFECTION

The effect of high energy electrons in destroying human pathogenic viruses in municipal sludge is being investigated in a companion study by Professor T.G. Metcalf of the University of New Hampshire. This work is supported by a separate NSF/RANN grant. Dr. Metcalf and his associates have measured the viral content of both influent and effluent Deer Island wastewater; they report that more than 80 percent of the viruses are collected in the raw sludge.

Viruses present smaller targets to ionizing radiation than do bacteria, and their D_{10} dose (for a 10-fold reduction) is correspondingly higher (Figure 4).[4] Fortunately, the virus content of raw sludge is about four orders of magnitude lower than its bacterial content.

Using radiation-resistant Polio II as the test virus, present results indicate that 400,000 rads are more than sufficient for the viral inactivation of digested sludge though a somewhat higher dosage may be desirable for raw, thickened sludge. The inactivation is not significantly affected by the organic content of the watery medium.

DE-INFESTATION

Pathogenic parasites, such as the ascaris worm, survive adverse soil conditions for long periods and can propagate from grazing animals to the human population or transfer directly from soil or plant to humans. Such infection has been a major concern of public health authorities in Switzerland and Germany[5]. Prior work at MIT on food parasites and their larva and ova indicates they present relatively large targets to ionizing radiations and should be destroyed by the 400,000 rad treatment. Studies are planned to confirm this expectation for sludge.

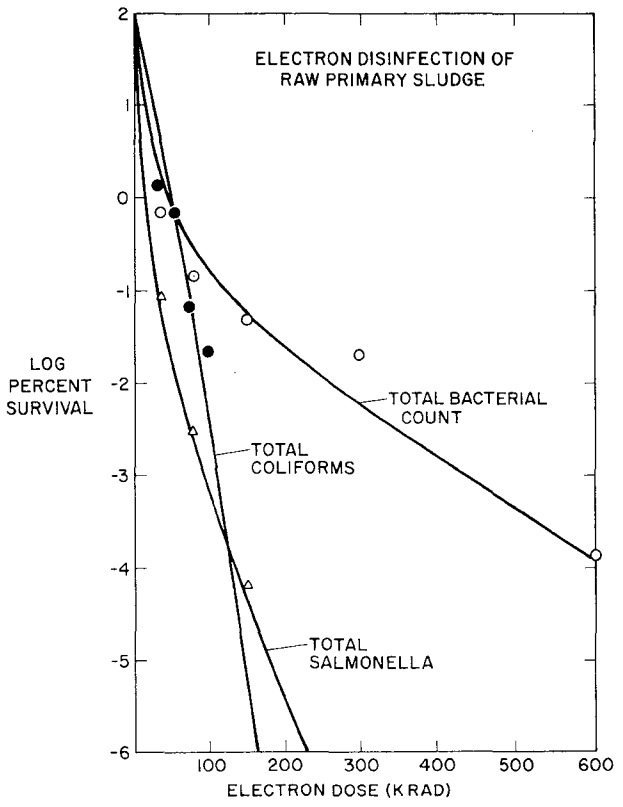

FIGURE 3—Electron Disinfection of Raw Primary Sludge

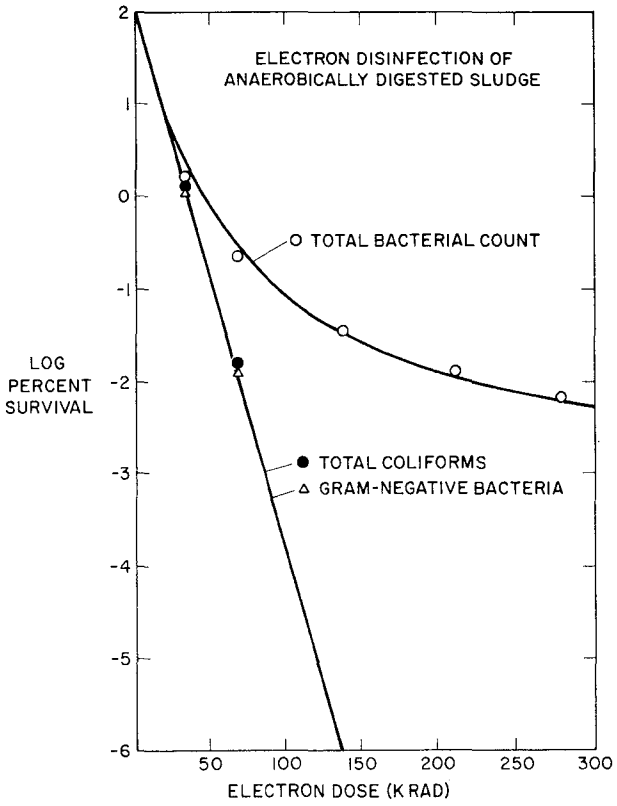

FIGURE 4—Electron Disinfection of Anaerobically Digested Sludge

DESTRUCTION OF TOXIC CHEMICALS

Electron irradiation may have additional beneficial effects for sludge reuse through the destruction of toxic chemicals. This aspect of the MIT project is being studied by Dr. Edward W. Merrill, Carbon P. Dubbs professor of chemical engineering.

High-pressure, liquid chromatography, and other analytical methods are being used to investigate the effect of electron treatment on pesticides, herbicides, and certain carcinogenic compounds found in municipal sludge. In an initial model system study of an aqueous solution of a PCB (3.4.2'-trichlorobiophenol), 90 parts per billion, the PCB was totally degraded by an electron dose of two megarads. An aqueous solution of monuron, a herbicide, was found to be degraded by the same dose. The detoxifying studies will proceed to irradiation conditions simulating sludge treatment.

SLUDGE FOR SAFE LAND APPLICATION

The disinfection of municipal sludge by treatment with high energy electrons would remove an important barrier to its safe utilization on land as a soil conditioner and plant nutrient. Electron disinfection thus opens attractive alternatives to incineration or deposition on land fills. The process is cost effective and requires far less energy than any other method.

Commercial electron accelerators already developed for industrial applications could be applied to sludge treatment modules of both higher and lower capacity than the Deer Island system. The method is applicable to distributed loads of moderate size such as the sludge produced at wastewater plants along river systems. Larger capacities for population areas such as New York, Chicago, and Los Angeles can be realized by paralleling identical modules. This achieves both a desirable redundancy and allowance for growth. The flexibility, safety, absence of radioactivity both in the source and the treated product, and compactness are attractive features of the electron approach to sludge disinfection and reuse.

CAPITAL AND OPERATING COSTS

The costs of sludge disinfection by high energy electron irradiation have been determined on the basis of the 50-kilowatt, modular system at Deer Island. For such 50-kW systems, the capital cost is estimated at $450,000, and the annual operating cost at $130,000. These estimates, in 1976 dollars, are based on the assumption that:

1. 400,000 rads is the disinfecting dose.
2. The electron utilization efficiency is 35 percent. This factor takes into account the electron beam losses in passing through the intervening air, in overscanning the sludge width, and in passing beyond the sludge thickness and the effect of nonuniform distribution of ionization within the sludge thickness. A utilization efficiency of 50 percent and higher is attainable.
3. Electric power costs three cents per kilowatt hour.
4. Linear depreciation is over 20 years and interest is at 10 percent averaged over 20 years.
5. Accelerator system costs $6,000 per kilowatt of output beam power.

TREATMENT COSTS VERSUS SOLIDS CONTENT OF SLUDGE

The liquid wastewater residuals disinfectable by a UNIT system equivalent to the Deer Island 100,000 GPD electron facility is 153,000 tons per year. The cost to disinfect this watery waste is $0.85 per liquid ton.

This annual throughput is independent of the solids content of the sludge. The dry tonnage treatable per year by the UNIT system is therefore directly proportional to the sludge SOLIDS content.

% SOLIDS at electron beam	Annual DRY TON throughput	Cost per DRY TON
5	7,650	$17.00
20	30,600	4.25
50	76,500	1.70

MODES OF UTILIZATION

The disinfection of sludge by high energy electrons can be applied to wastewater systems at several possible points in the process. Among these (Figure 5) are:

1. Prior to the subsurface injection of raw sludge using the multiple plow-furrow method. This mode of application avoids digestion and dewatering costs and retains the nitrogen nutrient. It relies on electron treatment for disinfection and de-infestion, and on natural soil-composting activities to stabilize the distributed solids. The estimated electron disinfection cost for sludge with five percent solids would be about $17 per dry ton.
2. Prior to subsurface injection but after digestion. This point of application does not eliminate digestion costs but reduces the necessity for high quality digestion. Although about half of the nitrogen content may be lost, a significant recovery of methane would be obtained from anaerobic digestion systems. Assuming the liquid volume has not changed, the estimated total electron disinfection cost would remain at $17 per dry ton.
3. After composting and before application on farmland or packaging for retail distribution. Because of the high solid content this point of application would require the smallest investment in electron treatment equipment. The estimated disinfection cost would be about $2 per ton.
4. Some evidence that treatment with ionizing radiations might improve the reliability of digestion and promote the dewatering of municipal sludges has been observed. Should further studies support these observations it may be advantageous to electron disinfect sludge before digestion, dewatering, and composting for general agricultural use.

All of these modes of application of electron treatment are directed to the return of municipal sludge to the soil for its substantial and traditional benefits to soil conditioning and plant growth.

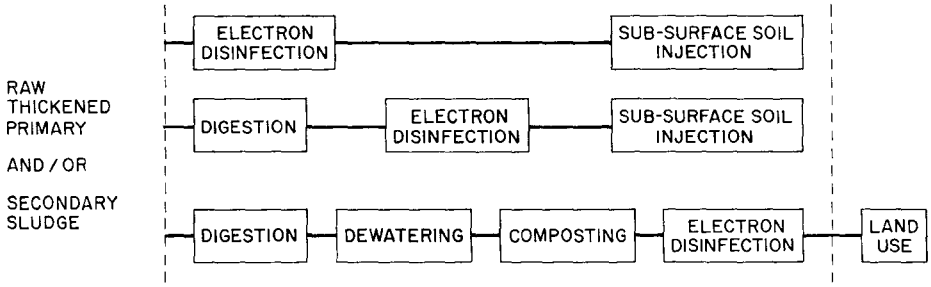

FIGURE 5—Options for Electron Disinfection

ACKNOWLEDGMENTS

The author takes pleasure in acknowledging the cooperation of his associates on this MIT-NSF/RANN project. Professor A. T. Sinskey, Department of Food Science, Nutrition; Professor E.W. Merrill, Department of Chemical Engineering; K.A. Wright, Co-director, High Voltage Research Laboratory; J.L. Danforth, Consultant, Department of Electrical Engineering and Computer Science; D. Shah, B. deBree, and R. Emanuelson, High Voltage Engineering Corporation; and Professor T.G. Metcalf, Department of Virology, University of New Hampshire. The assistance of members of the Deer Island Wastewater Treatment Plant and officers of the MDC Sewer Division is also gratefully acknowledged.

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Municipal Waste as a Resource: Discussion

QUESTION: I want to ask a question, then give my reasons for the question. Why all the emphasis on digestion? One of the reasons that I ask this is because anaerobically digested sludge is quite toxic, largely because of the ammonia content. Five hundred to 750/ppm of ammonium bicarbonate, much of which is lost in your stabilizing or aerating, is also lost from agriculture. We deliberately destroy half of the nitrogen value of sludge in the process of getting it on the land.

Ammonia is toxic, incidentally, to sprouting seedlings. You have to allow a little time in the soil. If you use Trump's approach and disinfect with electrons, I don't see that there is any need to digest before injecting into the soil and, as was pointed out, the cost of the treatment is very largely the cost of digestion. It is very hard to recover much of that cost as methane, though, incidentally, you can in the larger plants.

Now, there are plenty of places where you do need digestion, but where you are going into the soil or you are feeding earthworms, you want to give them the maximum amount of food. You don't want to destroy half of it first and produce a toxic, nitrogenous material. You will find the raw sludge, properly disinfected, may be much better.

DR. SMITH: I guess the major reason that we handle digested sludges primarily is because EPA, in its new proposals, seems to recommend digestion very strongly, prior to land application.

QUESTION: Certainly, they do.

DR. SMITH: We do have a site at Butte, Montana, which takes about 30,000 gallons of raw, stinky sludge every day and handles it beautifully, and this is not disinfected. It is in a remote location and I really couldn't see any point in disinfecting it if we wanted to. The ground water is probably at 300 feet or more, and it is a good application. However, John and I have the opinion that the treatment process is the place to cut the cost, to look at the system.

DR. HARTENSTEIN: We find in the sludges we have looked at that there is relatively little ammonia, relatively little nitrate, and a considerable amount of organic nitrogen, generally. If anything might be pointed at as being toxic to earthworms, we are thinking now that it will be sulfide, and that would be only in conjunction with an anaerobic digest, not an aerobic one. The aerobic digests are delicious to the earthworm. The earthworms go for aerobic digests far more than they go for any other kind of food you can make available to them.

DR. KORBITZ: Roy, in connection with that, you mentioned toxicity to the invertebrates early during your presentation. Do I understand that you are thinking that it is a sulfide rather than an ammonia toxicity?

DR. HARTENSTEIN: I don't believe that ammonia will be a serious problem to any soil invertebrate. In fact, one of the invertebrates we deal with is a prime producer of ammonia. Its entire output of nitrogenous end product is in the form of ammonia rather than in the form of urea or some other nitrogenous substance.

QUESTION: My question is directed to Dr. Trump. Have you considered a system where you would irradiate before you digest, and in this way, perhaps, enhance your stabilization and your digests by already breaking down some of the complex organic and other material in the sludge?

DR. TRUMP: Yes, we have considered such a system. The digester at Deer Island doesn't work too well. Sometimes it goes bad, and just because of the point you raised, we have considered giving it a mild dose to destroy the unfavorable structures in there and to allow it to seed itself with the hard-working bacteria of the proper anaerobic type. We have also considered systems in which we pre-irradiate sludge before digestion, so as to promote de-watering, and de-watering, as has been mentioned, is a very costly part of the whole operation. We are certain that a real improvement can come, but we are not able to make it very definite at this point.

I would like to echo what has been said by Jim Smith. I find a great deal of compatibility to what I heard on this program by Roy Hartenstein and Jim Smith. These three methods are all mutually consistent. Why digest if the soil will do such an excellent job of that? If we can avoid the destruction and vaporization of some things which might as well go into the soil for benefit, it certainly would reduce the cost and some of the anomalies.

QUESTION: I have two questions, one for Dr. Trump. I was with you when you showed the slides destroying the fecal choloform bacteria, but I was kind of turned off when you started breaking down PCBs. In other words, do you know what you are doing with the long chain or other type of chemicals? Are you creating, perhaps, more toxic materials that you don't know about?

DR. TRUMP: My associates feel that there is very little chance of producing somethings as bad as the PCB. Monuron was totally degraded, and we expect that

pesticides and herbicides generally will be degraded. That is to say, it was reduced into simple, not complex, but simple molecules, which were simple structures of these compounds.

In pressure liquid chromatography, the PCB and the monuron peak had totally disappeared. There were no fragments of somewhat similar size in the neighborhood. It was really reduced to simple structures of matter. From that point of view, it is quite evident we will be destroying a really present adverse chemical and replacing it with simple structures, which is our desire and which is in general the process of nature.

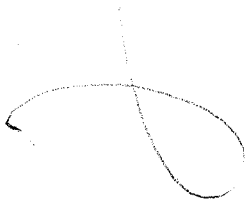
QUESTION: I might point out that carbon tet is a very simple structure. I was worried about that as being one of the products.

The second question is, Dr. Hartenstein, have you considered using your worms in the aerobic digester to more or less facilitate your process?

DR. HARTENSTEIN: That is an excellent suggestion, but not within the digester itself because—unless you select the proper worm such as the tubificid worm. I don't think much has been done on this, though. The worms we are dealing with are animals that don't like to swim a lot. They prefer to crawl.

QUESTION: This is an earthworm question for Dr. Hartenstein. Have you been testing your earthworms in all of the different varieties of chemically precipitated sludges as compared to normal secondary sludges? We seem to be reaching a point in time where the large amounts of sludge produced are heavily chemically precipitated and I don't know whether or not they are the proper environment for your worms.

DR. HARTENSTEIN: The closest we have come to that is to take sludge that has been treated with procol-738, which is a de-watering agent, and we find that the worms can consume sludge under conditions where you have about 1,000 times the level of procol-738 than is recommended by the producer who puts out this polyacrylamide. That is the closest we have come to what you are asking.



Roundtable Papers

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Validation of Evapotranspiration Concept: a Seven-State Test

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Most states have geographical areas with high water tables and/or soils that do not percolate well. Under such conditions, typical septic tank drainage fields do not function properly. The result is contamination of surface or subsurface water sources or underdevelopment of these land areas. Evapotranspiration is a potential alternative for treating household wastes in such areas. The environment has a significant effect on evapotranspiration, and performance data for the operation of these systems is very limited. Health department officials have been reluctant to utilize evapotranspiration technology because of the inability to predict system performance. This project will attempt to remove this barrier to technology transfer by evaluating the performance of evapotranspiration systems under widely varying environmental conditions. Successful completion of this research will result in policy decisions by the states regarding the use of evapotranspiration systems. Guidelines will be developed for the location, design, and operation of evapotranspiration systems for individual households, summer camps, recreation parks, etc.

This study is designed to determine the feasibility of using evapotranspiration as a method of disposing of household wastewater in cases where septic tank drainfields cannot be used satisfactorily. Specifically, the study will demonstrate the year-round performance of seven evapotranspiration systems under varying climatic conditions and will attempt to establish design criteria for such systems.

Most states, if not all, have geographical areas which must rely on septic tank systems for the treatment and disposal of household wastewater. Some of these areas have soil conditions which are not satisfactory for septic tank drainfields. These soil conditions occur when the water table is within three feet of the soil surface, or when the soil is too "tight" and the wastewater cannot percolate through the soil at the prescribed rate.

We became involved in this problem at the request of officials in Gloucester County, Virginia. At the time, the county was concerned about the curtailment of economic growth which might result from the high rejection rate of requests for septic tank disposal systems. This situation prohibits the use of land for housing development, causes prime agricultural land to be used for real estate development, lowers land values, and results in losses of tax revenue. In addition, failure of existing septic tank systems caused by these soil conditions results in contamination of water supplies and shell fish waters.

Further investigation revealed that the problem is quite widespread. Twenty percent of Virginia's population is served by this type of disposal system, but over one-half of the land area is unsuitable for septic tank drainfields. Approximately 10 percent of permit applications are rejected. It is estimated that between 6,000 and 10,000 existing systems are failing, and some states have failure rates as high as 40 percent.

The alternatives to soil disposal of wastewater are discharge into a stream or into the atmosphere. Discharge into a stream is not really feasible because of the extensive treatment required. Therefore, discharge into the atmosphere, termed evapotranspiration, appears to be the best solution to the problem.

However, at this point we encountered an additional problem. Although evapotranspiration has been used successfully in the western part of the United States, health officials would not approve installation permits for evapotranspiration systems. They were concerned

that evapotranspiration systems would not perform satisfactorily under conditions of heavy rainfall and cold, humid weather. Also, very little data were available on which to base design criteria. Therefore, it was necessary to conduct a field demonstration before evapotranspiration technology could be utilized.

Evapotranspiration is the removal of water by evaporation from the soil surface and by transpiration through grasses or plants growing on the surface. An evapotranspiration bed consists of a large excavation in the ground lined with plastic to prevent seepage into the surrounding soil, filled with a layer of gravel to provide storage space and with sand to provide capillary movement to the surface, and finally, a thin layer of top soil to support plant growth.

One of these systems has been installed in Delaware, Maryland, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia. The systems have been connected to homes which will provide typical sewage loadings such as effluent from garbage disposals, dishwashers, and washing machines, in addition to bathroom wastewater.

Each site has a weather monitoring station that continuously records temperature, humidity, wind velocity and direction, precipitation, and net radiation. Samples are collected weekly to provide data for calculating bed performance. The measurements will be collected for a 12-month period to provide an evaluation of these systems under a full range of climatic conditions.

Successful completion of this project will provide state health officials with factual information to define policies and regulations for the public use of evapotranspiration systems. The results will also provide basic data for predicting evapotranspiration rates and establishing design criteria. Land owners will have an alternative method of wastewater disposal, and therefore, additional land development opportunities. Failing septic tank systems can be corrected and contamination prevented. Detailed cost data will be obtained to benefit the public. A further application of this technology may also be made to multi-family dwellings, commercial establishments, and seasonal recreational facilities.

ROUNDTABLE DISCUSSION

During the roundtable discussion, a question was raised about the build-up of salts (particularly nitrates) in the sand portion of the evapotranspiration bed. At this time no specific information is available. Some systems in the West have been in operation for eight to 10 years and still appear to be functioning properly. A follow-up question concerned the use of other materials instead of sand. Fly ash is being used in one experiment. Peat and carbon-type materials were suggested as possible alternatives. It was mentioned that continuous monitoring of the liquid level in the bed would provide more information about system performance. This technique has not been used because of the additional expense which would be incurred.

Control of Virus Pathogens in Municipal Wastewater and Treatment Residuals

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R. Comeau

The enteric virus-inactivating effectiveness of high energy electron treatment of effluents and liquid sludge is being assessed at the Boston Waste Treatment Plant on Deer Island. The study is coordinated with a Massachusetts Institute of Technology study of the biochemical and economic feasibility of such treatment. Information on virus inactivation and factors either enhancing inactivation or contributory to virus radioresistance is being gathered. Natural virus numbers in sludge have been calculated by methods developed for measurement of virus in test samples. Laboratory data suggest virus pathogens in liquid sludge can be inactivated or controlled by radiation doses of 0.4 megarads or less. Confirmation of these data has been obtained from the results of in line treatment of liquid sludge at the Deer Island Plant. Virus inactivation by electron irradiation removes one of the potentially serious health hazards interdicting a liquid sludge land disposal policy.

This research project treats one of society's most perplexing problems: How to dispose of wastewater residuals without causing environmental problems, in a manner which is economically and scientifically feasible, and in a way which offers no health risk unacceptable to society as a whole.

The particular aspect of this problem addressed by the project is the elimination of a potential health hazard imposed by human pathogenic viruses, without jeopardizing the environment where wastewater residuals are disposed. The question asked is whether high energy electrons can be used successfully for disinfection of the virus content of municipal wastewater residuals. Project research is focused directly on removal of this kind of health hazard potentially dangerous to man. A question not asked but touched upon by project research is whether the method for removal of virus creates any further dangers for man or his environment. Unlike chlorine, high energy electron disinfection has no potential for causing damage to aquatic or terrestrial environments. If electron disinfection can remove viruses, subject to constraints of cost and scientific feasibility, wastewater residuals can be applied to land surfaces without danger of toxicity from the disinfection process.

The problems of waste disposal have been exacerbated by a number of factors, chief among which are the increasing tonnage of sludge residuals produced, the foreclosure of ocean dumping, and traditional burning disposal options, and the increasing need for reuse of water.

The drastic revision of standards of quality of treatment for effluent waste waters imposed by the Environmental Protection Agency has led to the realization that new and better treatment methods of more reasonable cost than the older methods are needed. Land disposal of human wastes has been in practice for centuries and land disposal of waste water residuals offers advantages today.

The virus study is based at the University of New Hampshire, but through coordination with an MIT study, makes use of the city of Boston Waste Treatment Plant on Deer Island and electron radiation laboratories at MIT. Both studies enjoy the cooperation of the Metropolitan District Commission of Boston. The MIT study is looking at the biochemical and economic feasibility of high energy electron treatment of sludge and wastewater. Regularly scheduled research conferences with New Hampshire

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and MIT project personnel in attendance offer opportunities to review research results and to discuss research plans.

Virus inactivation studies of factors influencing inactivation have been carried out at the High Voltage Research Laboratory at MIT. The purpose of these studies is to determine what radiation doses will prove necessary for inactivation of viruses found in sludge or wastewater effluents. Special attention has been directed toward factors enhancing radiation effectiveness. Evaluation of the effectiveness of electron treatment for inactivation of virus is being carried out at Deer Island, where a radiation unit has been installed which is capable of in-line treatment of 100,000 GPD of selected effluent or liquid sludge under controllable conditions of flow and irradiation.

Irradiation of virus was carried out in plastic dishes or aluminum tubes which were adapted to hold pressures up to 150 psi. The first experiments were designed to provide information on the radiation dose needed for inactivation of a selected enteric virus, and whether different enteric viruses might require differing amounts of radiation for inactivation. The dose needed for a 1 log reduction in virus numbers is referred to as a D_{10} value. Using poliovirus suspended in waste treatment plant effluents as a test system, a D_{10} value of 185 kilorads was obtained. This meant that an effluent containing between 100 and 1,000 plaque-forming units (PFU) of virus per gallon would require approximately a 370-kilorad dose per gallon for inactivation of virus. Comparison of D_{10} values obtained for five representative enteric viruses (adenovirus, reovirus, coxsackievirus B, poliovirus, and echovirus) showed poliovirus and coxsackievirus B to have the greatest radioresistance. These results suggested that a radiation dose lethal for poliovirus might be expected to be lethal also for a majority of the enteric viruses. This led to the use of poliovirus as a convenient test in experiments designed to provide information on radiation doses required for enteric virus inactivation, and the search for factors which either enhanced or decreased radiation effectiveness.

Tests conducted in parallel using small and large numbers of virus showed the radiation dose required for inactivation of virus is proportional to the number of PFU present. Plots of inactivation data for large and small numbers of virus produced inactivation curves of virtually identical slope.

No appreciable difference in virus radioresistance was detected when poliovirus was suspended in distilled water, waste treatment plant effluent, or the amino acid glycine. This result suggested ordinary amounts of organic matter encountered in wastewater would not significantly alter the virus-inactivating effectiveness of a given radiation dose.

No appreciable difference in the radioresistance of aggregated versus nonaggregated virus suspensions was found when stock suspensions were used. These data indicated aggregation of virus per se appeared to have little if any appreciable effect upon radiation effectiveness. A different result was found when aggregation took the form of virus absorbed to suspended solids in sludge. A protective effect was exerted by sludge. The protective effect could be visualized by examination of plots of virus inactivation curves. A shoulder was imparted to inactivation curves, contrasting sharply with the straight line inactivation curves obtained with tests of virus suspended in aqueous vehicles. The radiation dose required for virus inactivation was increased under these circumstances. The extent of the increase has not been determined accurately due to the necessity to fully evaluate the sensitivity and reproducibility of new methods developed for assay of virus in liquid sludge. D_{10} values of approximately 200 kilorads have been calculated for inactivation of test virus added to liquid sludge. If a virus content of 2 $\log_{10}$ PFU units per ml is assigned to the sludge, inactivation of all virus calls for a radiation dose of approximately 400 kilorads per ml.

Enhancement of radiation effectiveness by oxygenation of test virus suspensions could not be demonstrated. Oxygen pressures of 10 atmospheres (150 psi) failed to significantly alter the radiation dose required for inactivation of virus. Adjustment of pH to alkaline values of 10 had no appreciable effect upon D_{10} values. Acid pH values of three to four decreased D_{10} values and significantly enhanced radiation effectiveness by a factor of 2X.

Tests of Deer Island sewage samples were conducted periodically over a 10 month period to determine virus numbers and the influence of seasonal variations upon the numbers to be expected. The Deer Island Plant provides primary treatment of wastewater, followed by a 17- to 21-day digestion period. Methane gas produced during digestion is stored and used to help defray energy operating costs. Test results showed up to 90 percent of the virus content of influent sewage ended up in raw sludge. A concentration of 1,000 PFU per ml of raw sludge was calculated to be the maximum number likely to be found during peak virus periods throughout the year. Analyses of digested sludge showed a gradual decrease in virus numbers during the digestion period. At the end of 17 to 21 days, less than 1 PFU of virus per ml of digested sludge could be detected.

Reduction of virus numbers during the sludge digestion period simplified the task of inactivating all viruses left in the digested sludge. Remaining viruses could be inactivated by a dose of approximately 200 kilorads.

Evaluation of radiation effectiveness for sludge disinfection has been based on the assumption that a concentration of sludge would be necessary to detect low numbers of virus. Methods applicable to digested sludge have been examined first since this is the final wastewater residue product of the Deer Island Plant. Method development has taken into consideration the problems of virus adsorption to particulates and possibly encapsulation of virus within organic matrices. Method development has emphasized separation of fluid and solid phases of sludge, with recovery of virus from the solids. The method currently being tested is applicable to tests of samples of 25 to 50 gallons. Recoveries have been made from digested sludge of one-half or more of test virus added exogenously.

Virus assessment of the application of high energy electron radiation to a sludge disinfection objective indicates it is scientifically feasible. Controlled radiation

laboratory studies suggest a dose of 400 kilorads will inactivate or control the virus content of wastewater or liquid sludge obtained from the Deer Island Plant. No significant interference with radiation effectiveness attributable to organic matter, virus aggregation per se, or wastewater effluents was found. Inactivation of virus adsorbed to sludge solids required larger radiation doses than was necessary for inactivation of virus suspended in waste treatment plant effluents, but inactivation usually was accomplished by a dose of 400 kilorads. Enhancement of radiation effectiveness in the presence of a pH of three to four decreased virus-inactivating doses by a factor of two. Tests of the virus-inactivating effectiveness of in-line radiation treatment of effluent and liquid sludge at the Deer Island Plant confirm the disinfection capability of a 400-kilorad dose.

The ability to eliminate pathogenic viruses from wastewater residuals within accepted feasibility limits and without danger to man and his environment offers an attractive new approach to waste disposal problems. Elimination of virus removes one of the major public health constraints against the use of wastewater residuals for land beneficiation purposes. Under these circumstances wastewater residuals are converted from a national problem to a national resource of interest to local, state, and national governments.

Application of Viral Concentration Techniques to the Study of a Contact Stabilization Activated Sludge Treatment Plant

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Using poliovirus as a model system, viral association with suspended solids was demonstrated in laboratory adsorption studies. Infectious virus could be eluted from this adsorbed state. The virus-solids complex also was shown to be fully infectious in plaque assay systems.

Viral concentration techniques were developed which allowed recovery of indigenous virus from both the viral adsorbent and any naturally occurring suspended solids. The modified technique employing bentonite was applied to monitoring indigenous enteric virus levels within a contact stabilization activated sludge treatment plant.

The field data obtained demonstrated rapid adsorption of enteroviruses to the mixed liquor suspended solids. Further, a significant amount of infectious indigenous enteric virus was recovered from the sludge, indicating a slower inactivation process following the initial adsorption. Under normal operating conditions where the designed plant capacity was not exceeded, the contact-stabilization process removed 91 to 97 percent of the enteric viruses originally present in the raw wastewater.

Increasing demands placed upon water resources throughout the nation have necessitated a closer evaluation of both wastewater treatment and disposal. The public interest demands that domestic wastes be handled in such a manner as to minimize health hazards posed by a wide variety of potential pathogens including bacteria, protozoa, helminth parasites, and viruses.

To evaluate the problems posed by human enteroviruses present in domestic wastewater, an NSF/RANN-funded study was initiated under the title of "Viruses, Sewage, and Terrestrial Waste Disposal." This study sought to monitor the fate of viruses during wastewater treatment and in soil systems after effluent discharge onto land.

The first phase of project research evaluated select biological treatment processes. Efforts to study the viral removal capabilities of activated sludge treatment began using bench-scale models. Poliovirus was used in laboratory studies since this virus constitutes a large proportion of the indigenous viral population in most urban sewage. Additionally, poliovirus bears a close physical resemblance to the implicated agent of waterborne hepatitis.

Poliovirus distribution in a conventional activated sludge system was followed during a four-hour aeration period. The loss of infectious viruses from the supernatant phase was accompanied by the appearance of infectious viruses in the mixed liquor suspended solids. While 99 percent of the infectious poliovirus had been removed from the liquid phase within one hour, almost 90 percent of these virions were recoverable from the mixed liquor solids at four hours. These observations indicate that viral removal from sewage by adsorption to sludge solids is much more rapid than the subsequent viral inactivation within the solids matrix.

In further elaboration of these bench-scale studies, it was concluded that the performance of a conventional activated sludge process in inactivating poliovirus was independent of organic loadings ranging from 0.23 to 0.51 lb BOD_5/lb MLSS-day and hydraulic detention times within the range of five to 15 hours. Furthermore, the contract-stabilization process with a contact time of as low as 16 minutes resulted in the removal of poliovirus at the same efficiency as the conventional treatment, indicating that poliovirus adsorption to sludge was almost immediate.

Having established a laboratory model, a field study was initiated at the Govalle Wastewater Treatment Plant located in Austin, Texas. The purpose of the study was to

*Presenter

evaluate the extent of indigenous enteric virus removal in an operating treatment plant.

Since indigenous viral numbers were too low to allow quantitative recoveries by direct plating of samples, a method was developed to allow the concentration of viruses from wastewater. Bentonite clay was added to field samples. The addition of divalent cation at pH 6 then facilitated the adsorption of viruses onto the clay particles. Collection of the bentonite and elution of the viruses in a reduced volume allowed a 100-fold reduction of the sample with an average recovery efficiency of 52 percent.

Mixed liquor suspended solids were collected by settling and low-speed centrifugation. The solids were resuspended in an eluting medium and homogenized. Following recentrifugation, the eluates were assayed for viral infectivity.

The portion of the treatment plant studied has a designed capacity of 10 MGD. The plant operates in a contact-stabilization mode with a designed contact time of 20 to 30 minutes followed by a four-hour sludge stabilization period.

Indigenous enteric virus levels detected in the raw wastewater entering the plant remained fairly constant at around 1,000 plaque-forming units (PFU) per liter with a decrease to only 250 PFU per liter during a low flow period (Table 1). Heavy rains which occurred after day 283 resulted in what appeared to be a flush of the wastewater collection system on day 288 with enteric virus levels reaching 1,500 PFU per liter as the plant flow increased to 15 MGD.

Table 1—Virus Removal Efficiency of the Contact Stabilization Process, Govalle Wastewater Treatment Plant

Day	Raw Wastewater (PFU/l)	Clarified Supernatant (PFU/l)	Virus Removal (%)
260	1,180	90	93
262	760	40	95
269	770	70	91
274	1,290	40	97
276	1,150	50	96
281	250	8	97
283	570	40	93
288	1,490	310	79
290	140	30	79
295	170	50	71

The distribution of enteroviruses between the liquid and suspended solid phases of mixed liquor samples paralleled previous laboratory observations. Virus levels in the supernatant ranged from a low of approximately 10 PFU per liter to a high of 300 PFU per liter. Sludge-associated virus levels consistently ranged five- to 10-fold greater then "free" virus, reaching 1,000 PFU recovered from the solids of a one-liter volume of mixed liquor.

The viral removal efficiency of the contact-stabilization process during the field study ranged from 70 percent to 97 percent (Table 1). Under normal operating conditions, greater than 90 percent of the detectable incoming viruses were removed from the wastewater. During that period of time when plant flow exceeded designed capacity because of heavy rain (days 288, 290, 295), only 70 percent to 80 percent of the influent virus were removed.

The bentonite concentration technique also was used in attempts to recover viruses leaving the treatment plant from the chlorine contact tank. Within the sensitivity limits of the methodology used, effluent virus levels appeared to be no greater than 10 PFU per liter. Therefore, the chlorination employed at the plant provided an adequate backup system insuring at least a 100-fold reduction in virus levels, even during the period of plant overload when the removal capability of the contact-stabilization process was at its lowest.

The results of the field study reaffirm the effectiveness of the activated sludge process in removing viruses in a well-operated treatment plant. Virus transfer from the raw wastewater to the activated sludge solids is relatively rapid. However, total inactivation of sludge-incorporated virus is not a synonymous occurrence. Since infectious virions can be recovered from sludge solids over a prolonged period of time, serious consideration must be given to subsequent handling of wasted sludges.

Once viewed as a liability, domestic wastewaters, treated to minimize health hazards, may be viewed more properly as an integral part of the water resources of the country. Secondary biological treatment coupled with effective disinfection is capable of achieving a 99 percent reduction of indigenous viruses.

Wastewater sludges may be expected to carry a higher load of potentially pathogenic organisms, including enteroviruses. Emphasis must be placed upon adequate treatment of these residuals to insure the inactivation of pathogenic agents prior to the disposal of wasted sludges into soil systems.

Surface Application of Municipal Effluents

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Movement of poliovirus I (Chat) through nonsterile core samples of a sandy forest soil was monitored, using several regimens of loading with either dechlorinated final effluent from an operating activated sludge treatment plant or distilled water. Simulated cycles of rainfall and effluent applications, resulting in ionic gradients, were shown to affect virus movement. Such studies indicate that poliovirus applied in effluents may move considerable distances through this soil after rainfall. The capacity of surviving virus to migrate was unchanged after 84 days soil incubation at 4°C and 20°C. Representative field data from areas of low and high precipitation are discussed and shown to be consistent with the dynamics of virus release developed in this model system.

*Presenter

Moore and her co-workers have shown that in a well-operated contact stabilization activated sludge treatment plant, 90 to 95 percent of the indigenous viruses become sludge associated. Metcalf has shown us the impact of irradiation using a four million electron volt Van de Graaf accelerator on viruses in primary sludges. His results suggest complete inactivation of a broad range of viruses when given sufficient treatment.

Being reasonable, I know that not all plants are well operated, and that all plants do not work within design capacity. Many of us are called upon to serve as expert witnesses as regulating agencies attempt to bring municipalities into line with long-standing regulations.

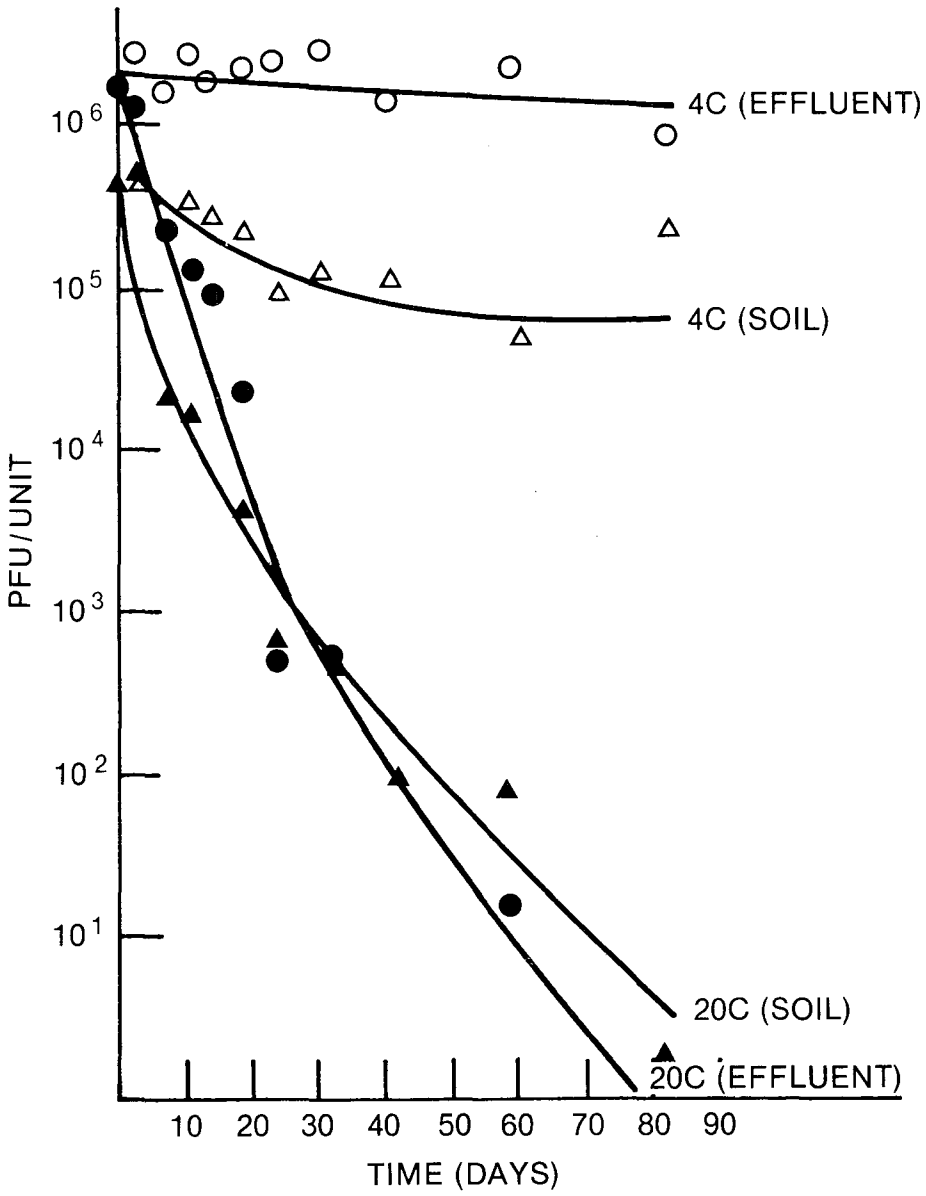
Even within well-operated plants, some viruses escape treatment and are distributed to the soil. Foster and Engelbrecht have recently (1973) estimated the numbers of wastewater pathogens applied to the soil. Starting with an assumption of 4×10^{10} virions per million gallons of raw wastewater—a fairly typical level—and making an assumption that the primary effluent had become reduced in viral content by 50 percent, they had 2×10^{10} virions in the primary effluent. Assuming 90 percent efficiency of removal of virus by secondary treatment (a figure confirmed by Moore's work), this released for disinfection purposes 2×10^{9} infectious virions. Making an assumption that chemical disinfection would be 99.9 percent effective, they were left with 2×10^{6} infectious virions per million gallons. Should this material be discharged to the soil for irrigation purposes at the rate of two inches per week, Foster and Engelbrecht calculated that 1.6×10^{4} viruses would be applied per acre, per day.

Moore's data indicate that activated sludge serves to concentrate 90 to 95 percent of the indigenous viruses found in the primary wastewater: The numbers of potential infectious virions released to the soil by the use of sludge as a soil conditioner may be at least as great as that released in effluents. This, of course, depends on the treatment accorded the secondary or primary sludges.

The questions I want to address in this roundtable are:

1. Will human enteric viruses survive in the soil?
2. Will they move with water flow through the soil?
3. Are the answers to (1) and (2) above, such that we can generalize?

To answer these questions I should like to show the summary data of two experimental series. The first set of data



taken from Duboise, Moore, and Sagik (1976) demonstrates the ability of poliovirus to survive in soil. Obviously, the rate of decay is greater at 20 degrees than at four degrees, but survival for a prolonged period of time has been demonstrated. The second experiment is taken from the same study by Duboise et al., and demonstrates the movement of viruses through the soil as a function of changing ionic milieu. This change is brought about by precipitation. The degree of precipitation will be reflected in the rate of viral movement through soil cores.

The third question I listed was: Can we generalize from those two observations? Any atlas will tell you that total annual precipitation in the area of the Flushing Meadow project in Arizona is 10 cm or less. It will also tell you that St. Petersburg-Tampa has a mean annual precipitation approaching 250 cm. Atlases—or travel—will tell you that four degrees is not unusually cold as a soil temperature in Michigan or Colorado, and 20 degrees may be a reasonable measure of subsurface soil temperatures in the Southwest.

Table 1—Estimated Wastewater* Viruses Applied to Soil[1]

Raw	Primary Effluent	Secondary Effluent	Disinfection	Virus/Acre/Day
4×10^{10}	2×10^{10} (50% removal)	2×10^{9} (90% removal)	2×10^{6} (99.9% removal)	1.6×10^{4}

[1] Per million gallons.

Table 2—Poliovirus Profiles in a Series of Soil Cores Dismantled at Various Stages of the Sequential Elution Process

Depth in core (cm)	Viral distribution (% of total PFU applied)						
	Initial Inoculum +	500 ml of effluent +	100 ml of water +	100 ml of water +	100 ml of water +	100 ml of water +	100 ml of water +
2	55.2	66.0	52.0	12.0	36.0	21.0	11.0
4	0.4	3.4	3.9	3.0	5.0	6.1	4.5
6	0.1	0.6	2.7	18.0	13.0	7.3	2.5
8	<0.1	0.6	6.8	3.6	1.7	1.8	1.5
10	<0.1	0.3	3.2	1.8	1.0	2.1	1.4
12	<0.1	0.1	2.3	1.9	1.6	1.5	1.4
14	<0.1	0.1	1.3	1.5	1.3	1.6	1.7
16	<0.1	<0.1	0.6	1.3	1.4	1.5	1.5
18		<0.1	0.3	1.4	2.1	2.0	1.7
Core eluate	None	<0.1	3.2	13.3	8.2	14.0	43.3
Total recovery (%)	55.7	71.1	76.3	57.8	71.3	58.9	70.5

These observations lead me to conclude that (1) viruses have a finite survival probability in soil. This is more important in cool climates and with effluents and sludges from overloaded plants than it is in warm climates and in properly operated plants; (2) viruses, like any other charged macromolecule, move as the ionic climate or medium permits; and (3) what works and is appropriate in Arizona may not be wise in Tampa; what's great for Lubbock may be foolish in Muskegon.

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ROUNDTABLE DISCUSSION

Electron radiation treatment of sludge for virus disinfection or sterilization purposes is applicable to liquid raw primary, digested primary, waste activated secondary, centrifuged, or dry composted sludge. It was pointed out that removal of potential health hazards caused by virus pathogens (and probably bacterial and protozoan also) would make possible realization of important advantages to be gained from direct application of raw primary sludge to land. Benefits to be gained from the absence of further plant treatments included avoidance of toxic quality imparted to soil microbial populations, loss of nutrient materials, and added treatment costs.

5

ENVIRONMENTAL CONTAMINANTS

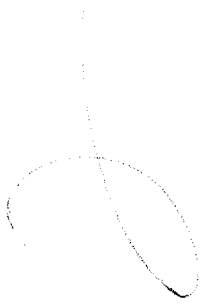
5. Environmental Contaminants

RANN supports research to identify, understand, and reduce contamination arising from the manufacture, use, and disposal of chemical products. Trace contaminants in the ecosystem were analyzed by the following research projects which were part of a panel presentation.

RANN cosponsored studies on airborne pollutants and the development of an experimentally validated model for chemical and physical transformations, including gas-to-gas conversions and gas-to-particle conversions (Pitts). Pesticides and other chemicals of commerce are studied through analyses of soil, run-off water, and agricultural crops for derivations which could have been formed by nitrosation with soil nitrate (Fine). Irrigation for minimal nitrate pollution is being used to develop a capability to predict the amounts and concentrations of nitrate in water that percolates through the root zone of soils of irrigated lands (Pratt). An accident in Michigan introduced the highly toxic PBB contaminant into the environment, and a RANN research project is investigating the cost of this accident in terms of animal products used for human consumption. The project report contains discussion of the role of scientific data and science committees in debates over safe limits for this environmental contaminant (Taylor).

A separate roundtable considered measurements of the concentrations of gases and the size distributions and compositions of particles emitted from major air pollution sources that are normally found in U.S. metropolitan areas. Preliminary studies indicate that coal-fired power plants release far greater quantities of carcinogenic polynuclear aromatic hydrocarbons than was previously thought (Gordon).

Panel Papers



Introductory Remarks by the Panel Chairman

James N. Pitts, Jr.
Director, Statewide Air Pollution Research Center, University of California, Riverside,

It is a pleasure to welcome you to this panel on environmental contaminants. Our speakers are researchers in industry and universities deeply involved in programs directed not only toward understanding but also to finding *solutions* to certain serious environmental problems. These programs reflect the rapidly growing number of environmental threats to our health and welfare. A discussion of four specific cases involving the nature and impact of trace contaminants in air, water, and land—indeed an entire ecosystem—should serve to illustrate the enormous challenges facing all elements of our society as we attempt to achieve acceptable compromises among energy, economics, and environmental quality.

Furthermore, the four reports taken together are indicative of the well-coordinated, problem-oriented approach taken by the National Science Foundation in its efforts to meet such challenges through its program of Research Applied to National Needs. It recognizes the commonality of certain problems encountered when one seeks a detailed understanding of the physical, chemical, biological, and socioeconomic impacts of all types of trace environmental pollutants. For example:

- One is dealing with concentrations of contaminants which are generally at very low levels, except, of course, in special situations.
- Generally, a given environmental contaminant is present in a complex mixture with a wide variety of organic and inorganic compounds that may be gaseous, liquid, solid, or, indeed, in some intermediate form (e.g., adsorbed on a particle).
- In following the course of a specific contaminant through the environment, the compound in question is exposed to a variety of chemical and physical stresses, such as heat, cold, light, moisture, and oxygen. The introduction of light and oxygen, along with the effects of heat, moisture, etc., make elucidation of the mechanisms of chemical and physical transformations of pollutants very difficult. Thus, we are not dealing with a simple, isolated laboratory reaction.
- The chemical or physical analysis of a specific environmental contaminant may itself require highly specialized apparatus simply because of the low concentrations involved. But an even

more difficult task is the identification of one compound at a low level in a host of others, each of which may give "signals" which interfere with the particular characteristic one is seeking in the target contaminant. In short, the separation of an environmental contaminant may be a much more difficult job than its final identification.

Of course, the bottom line in environmental research, the determination of the impact on man's health of a trace contaminant which may be present with a variety of other compounds with which biological, physical, or chemical synergisms may occur, is an almost overwhelming task. Clearly, determination of the effects on man of typical ambient levels of environmental pollutants, whether in air, water, or soil, will not be resolved in any short-term "crash" program. This fact is well recognized in the RANN philosophy.

Also clear is the fact that in the establishment of dose-response curves for the elucidation of such long-term health effects, it is essential to identify and quantify the "dose"—that is, the nature and degree of human exposure to the trace ambient levels of environmental contaminants. Examples of how this is being implemented in several RANN programs will be furnished by today's speakers.

Finally, when considering the impact of trace contaminants on man and his ecosystem, a division of the problem into the various elements of an environmental information and management system is useful. In a simplified form, these divisions involve knowledge concerning kinds and levels of emissions; pollutant transport in the environment; chemical, physical, and biological transformations of pollutants; and determination of environmental levels and effects of pollutants. To complete this system, appropriate legislative, control, and enforcement actions are essential.

Figure 1 shows such a systems approach for air pollution, but obviously it is also applicable to pollutants in water and soil. Clearly, a weak link (e.g., a poor or nonexistent scientific data base in any of the elements of such a system) can, in the final implementation of a control program, lead to serious mistakes which will be costly in time and money. Unfortunately, today, as a prominent EPA health scientist, Dr. John Knelson, said recently, "We are making multibillion dollar decisions about controlling air pollution on a 25-cent data base." In

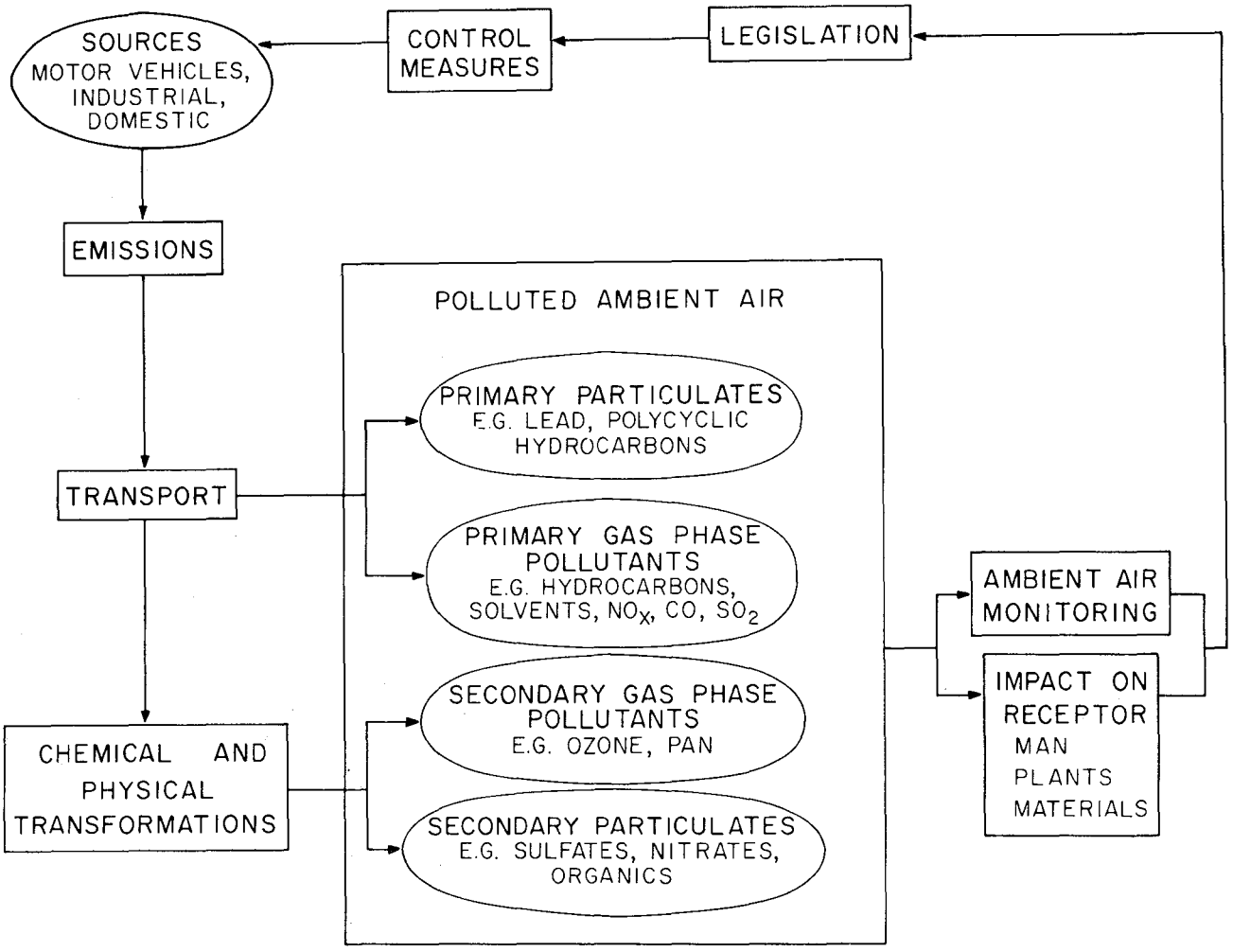


FIGURE 1—Simplified Air Pollution "System"

that case he was referring to the status of our current knowledge of the effects of sulfate particles on man's health. His statement can be applied to many, if not most, other areas of the environmental sciences. Happily, significant improvement in the quantity and quality of our nation's scientific and technical data base has been, and continues to be, a key goal of NSF/RANN and the investigators who are conducting problem-oriented research under their sponsorship.

On this note let us now turn to the first paper of this session.

Chemical and Physical Transformations of Atmospheric Pollutants

James N. Pitts, Jr.
Director, Statewide Air Pollution Research Center, University of California, Riverside

Cost-effective strategies for the control of air pollutants must be based upon a sound understanding of all elements of the air pollution system: sources, transport, and transformations, as well as impact on the receptors. Pressing needs include accurate and comprehensive emission inventories, reliable information on health effects at ambient levels, and a detailed understanding of complex chemical and physical transformations in the atmosphere. Our SAPRC-RANN research program focuses on the development of an experimentally validated model for such transformations, including not only gas-to-gas conversions (e.g., ozone from irradiated hydrocarbon-No_x systems), but also gas-to-particle conversions (e.g., the formation of sulfate, nitrate, and organic aerosols from their gaseous precursors). Smog chamber and ambient air data generated under this RANN program have been applied to control issues such as hydrocarbon reactivity scales and hydrocarbon-NO_x-oxidant relationships. Assessments of present and future energy constraints upon air quality, including the impact of offshore oil drilling and associated transport and refining operations, and the change-over from natural gas to sulfur-containing fuels are further applications of our SAPRC-RANN model.

A detailed understanding of the relationships between pollutant emissions and ambient air quality is crucial for the development of air pollution control strategies and the implementation of cost-effective control programs. Such relationships are often expressed in the form of mathematical models. These are complex, even or "nonreactive" primary pollutants such as carbon monoxide. However, the latter are relatively simple compared to those that must be developed to predict the impact of such noxious, toxic *secondary* pollutants as ozone (O_3), nitrogen dioxide (NO_2), and peroxyacetyl nitrate (PAN) on health and welfare. These constituents of photochemical oxidant (though by no means the *only* toxic species present) are formed not only in urban areas but also in rural areas by the action of solar ultraviolet radiation on the precursor primary pollutants, hydrocarbons (HC), and oxides of nitrogen (NO_x).

Adding to the complexity and toxicity of photochemical smog is the formation of particulates by gas-to-particle conversion processes. Thus sulfate, nitrate, and organic particles are also formed in the atmosphere from the corresponding gaseous precursors (SO_2, NO_x, and HC). Such secondary aerosols fall in the $\sim$0.1-1$\sim$ m size range where they are highly efficient both in penetrating the respiratory system and in scattering light, thereby reducing visibility. Thus, models predicting the impact of photochemical smog must include submodels describing not only the formation and behavior of gaseous but also of particulate pollutants.

Space limitations preclude extensive mechanistic discussions here. However, chemical and physical transformations in photochemical smog have been recently reviewed with support, in part, from our NSF/RANN grant.[1,2] These articles may be consulted for a discussion of the subject and references to the original literature.

RESEARCH OBJECTIVES

The prime objectives of our NSF/RANN program are:

- The achievement of a better understanding of the complex chemical and physical transformations occurring in photochemical smog.
- The organization, interpretation, and dissemination of our results, together with those from other laboratories (in particular, those conducting companion NSF/RANN research programs in trace

environmental contaminants), into formats that are of direct use to industry and to local, state, and federal air pollution control agencies.

Information of the type being generated in this program is required not only in current air pollution control programs but also as input into a variety of alternate control strategies. Applications for such information range from environmental impact statements for planned industrial expansions to the assessment of energy-environment trade-offs. In this regard, we might note parenthetically that smog chamber and ambient air data generated with this NSF/RANN support already have been applied to such control issues as the development of hydrocarbon and solvent photochemical reactivity scales,[3-5] and the impact of increasing use of high-sulfur fuels on particulate sulfate levels.

Our general approach at the University of California Statewide Air Pollution Research Center (SAPRC) to meeting the major goals of our NSF/RANN program has been through the development of a detailed, *experimentally validated* kinetic-computer model for the chemical transformations cited above. As seen in Figure 1, such a model is a crucial input into an overall airshed model capable of providing valid predictions of the effects on ambient air quality of relative and absolute changes in primary emissions as well as the effects of meteorology and topography.

As is evident from Figure 1, our SAPRC-RANN model has, as major inputs, current chemical theory and existing kinetic and mechanistic data. Our model also must be capable of predicting time-concentration profiles not only of the reactants and major products (i.e., hydrocarbons, NO_x, and O_3 and PAN) formed by irradiation of a variety of simulated polluted atmospheres in our environmental chambers, but also of minor products of great mechanistic and toxicological significance, such as formaldehyde, nitric acid, formic acid, and other noncriteria pollutants.

Furthermore, as stated earlier, it is essential to include *heterogeneous* processes into our SAPRC-RANN model. Thus, another major objective of our program is to

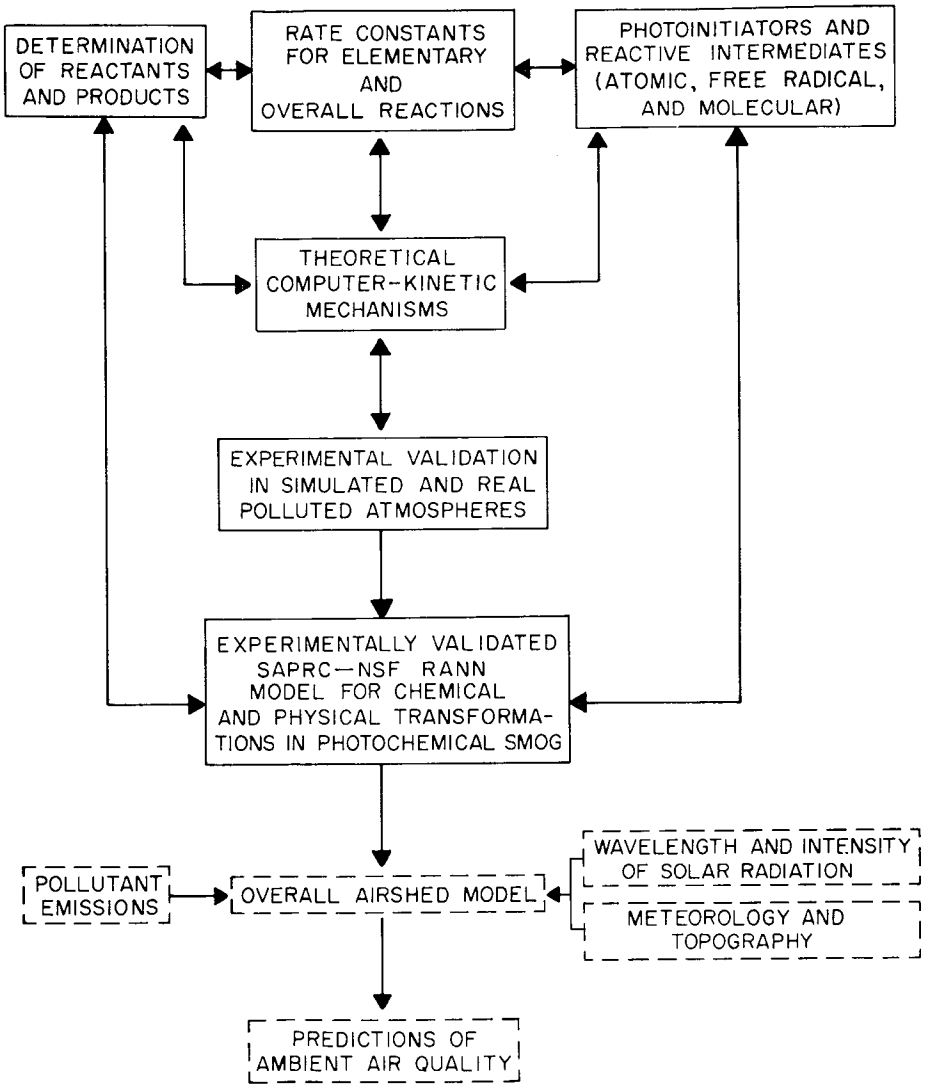


FIGURE 1—Inputs into model for chemical and physical transformations in photochemical air pollution.

generate a detailed and accurate data base for ambient aerosol levels at selected sites where significant impacts on people are likely to occur and to utilize these data in the development of more refined mechanisms for gas-to-particle conversions in both simulated and real atmospheres.

Our overall objectives, cited above, have been broken down into a series of *specific* goals. These start with the development of relatively simple models for single hydrocarbon-NO_x-air systems and ultimately will lead to a more general and far more complex model that can satisfactorily account for the reactions of mixtures of alkanes, alkenes, and aromatics.

For example, we have, as shorter term objectives in our overall development of the HC-NO_x-oxidant model, the investigation of the effects on oxidant production of such parameters as: (1) intensity and wavelength distribution of solar energy radiation, (2) total pressure, (3) relative humidity, and (4) temperature. In terms of the immediate application of such studies, the question arises: Could the rather substantial photochemical smog problems experienced by the high altitude cities of Denver and Mexico City be enhanced by the reduced atmospheric pressure and increased solar ultraviolet radiation of their atmospheres?

As another major research thrust of our NSF/RANN-sponsored program, we are currently evaluating the potential significance of a number of noncriteria, gaseous and particulate pollutants in photochemical smog. These are pollutants for which no federal air quality standards have as yet been promulgated, but which may in fact have significant effects upon the health and welfare of the American people. Current and projected studies include, for example, an initial evaluation of the impact of amines on oxidant and particle formation when they are irradiated with air-HC-NO_x mixtures. Among the concerns here is the question of whether nitrosamines may be formed from the corresponding amines in photochemical smog. This research task, incidentally, correlates very well with the important work of Dr. Fine and his coworkers at Thermo Electron Corp., who are conducting studies on the importance of nitrosamines in the environment with support from the Trace Environmental Contaminants Division of NSF/RANN.

Additionally, we have been concerned about the possibility of mutagenic activity in aerosol samples collected in ambient air throughout a major air basin which experiences both photochemical and London-type smog. Initial studies have been completed with NSF/RANN support, in collaboration with Dr. V. Simmon of the Stanford Research Institute who carried out the biological assays using the "Ames technique."[6] Our results currently are being written up for publication, and we shall only mention here that mutagenic activity was found in aerosol samples collected at various sites throughout the South Coast Air Basin.

FACILITIES EMPLOYED AND RESOURCE SHARING

Figure 2 shows our "state-of-the-art" evacuable smog chamber and its associated apparatus, including the SAPRC solar simulator and Fourier transform infrared (FT-IR) spectrometer. Incidentally, this facility is an excellent example of our policy of cost-sharing the acquisition of complex and expensive facilities and equipment. Thus, the California Air Resources Board (ARB) funded the design, construction, and installation of the chamber and solar simulator (at a cost of about one-third of a million dollars); the EPA has funded a number of pollutant monitors and other instruments, while NSF/RANN provided funds for the FT-IR spectrometer and its associated, highly complex computer hardware and software, as well as for a combined gas chromatograph-mass spectrometer-data acquisition system shown in Figure 2.

Similarly, the ARB mobile laboratory for aerosol research, developed for an earlier program at a cost of about one-half million dollars, has been operated by SAPRC research staff for the past year and a half. This facility is used extensively for our ongoing NSF/RANN aerosol program, as well as for our ARB-supported research.

SELECTED RESEARCH RESULTS TO DATE

In addition to results cited above (e.g., mutagenic studies), a number of accomplishments from our SAPRC-RANN program are cited below. For a full description of all results to date, our annual progress reports should be consulted.[7,8,9]

Modeling and Chamber Studies

The SAPRC-RANN model for the photooxidation of two representative hydrocarbons, propene and n-butane, with NO_x in air has been completed and consists of a 75-step detailed mechanism.

Preliminary work has been carried out in extending our detailed butane model to larger alkane systems. Models have been constructed and tested for the n-pentane-NO_x and n-hexane-NO_x systems and include intramolecular isomerizations of alkoxy radicals which we have shown to be important in these systems.[10,11]

A "semi-lumped" parameter model has been developed for alkanes which gives agreement comparable to the detailed models when compared to evacuable chamber data obtained for the irradiation of alkane-NO_x systems for as long as 10 hours.

Upon incrementally increasing the short wavelength component of the UV photolyzing radiation while maintaining a constant integrated light intensity (i.e., constant rate of NO_2 photolysis, k_1), significant enhancement was observed of the smog manifestations measured in environmental chamber irradiations of a propene-n-butane-NO_x -air system.[12] For example, the ozone maximum increased from 0.57 to 0.70 ppm and occurred after 2.5 hours of irradiation instead of 5 to 6.5 hours when the short wavelength cutoff of the Pyrex filter being employed was decreased by 14 nm (at the 50 percent T point). These observations are being used to further validate the SAPRC-RANN detailed kinetic model.

Atmospheric Studies

Meteorological variables [temperature, relative humidity, wind speed and direction, total and ultraviolet light intensities, gas phase pollutants (O_3, CO, NO, NO_2, SO_2,

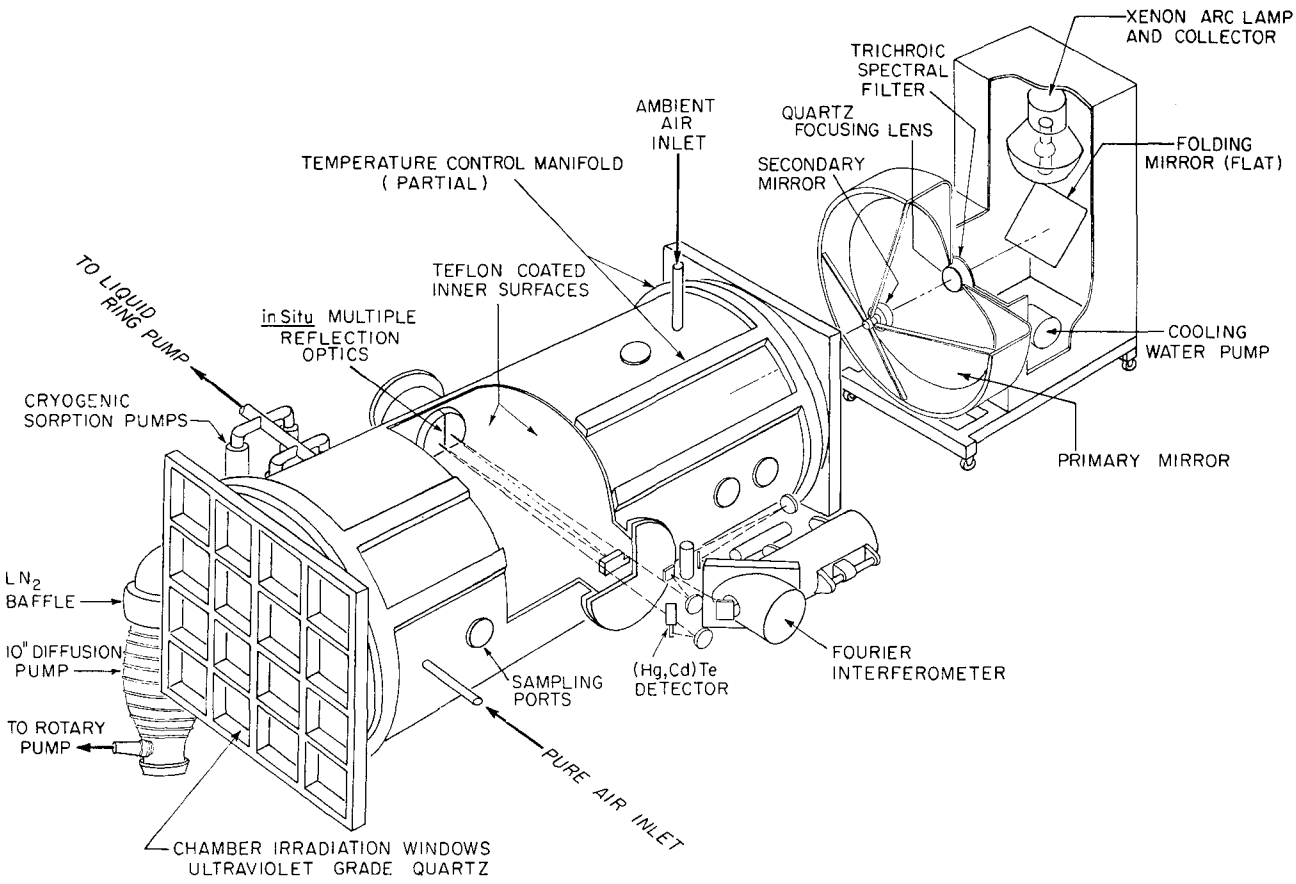


FIGURE 2—SAPRC 5800-liter evacuable chamber and 25-KW solar simulator facility.

PAN (peroxyacetyl nitrate), total hydrocarbons, and CH_4] have been continuously monitored using the full instrumentation of the ARB mobile laboratory. A complete air monitoring data bank has thus been recorded and has already been extensively used in interpreting the aerosol chemical composition data.

Twenty-four-hour particulate samples have been collected daily on glass fiber filters and subsequently analyzed for sulfate, nitrate, and ammonium ions as well as for their total organic carbon content. Analysis of the 176 24-hour samples collected during the six-month period, May 1 to October 31, 1975, shows that during that period, total suspended particulate (TSP) levels exceeded the federal air quality standard (75 μ g m^{-3} AGM) on 157 days. High nitrate, sulfate, and organic carbon levels were measured, with highest 24-hour concentrations of 70.2, 48.7, and 26.7 μ g m^{-3}, respectively. The high values for nitrate particulates, for example, are of significance since it has been stated that health effects may occur at levels as low as 8 μ g m^{-3}.

From the ambient air data accumulated during the first six months of our study, we have assessed the relative contribution of the major aerosol constituents to visibility degradation and found that sulfate aerosols are most efficient in scattering light.

During the four-day period from August 11 to 14, 1975, routine monitoring procedures were supplemented by collecting two-hour (daytime) and six-hour (nighttime) size-resolved particulate samples using five-stage impactors. Results show that both the organic carbon levels in particles smaller than 0.6 μ and their ratio to total particulate organic carbon closely follow the ozone diurnal profile, thus indicating that appreciable amounts of submicron organic aerosol are generated during periods of photochemical activity.

During two four-day periods, July 9 through 12, and August 11 through 14, 1975, a detailed study of the gaseous and particulate pollutants present in ambient Riverside air was conducted. Analyses of the gaseous samples by gas chromatography showed the presence of 38 different hydrocarbons. Particulate samples were analyzed by high resolution mass spectrometry-thermal analysis; more than 70 particulate organic compounds were identified. These included a variety of oxygenates such as aliphatic and aromatic carboxylic acids, nitrate esters, and other mono- and difunctional compounds. These oxygenated compounds are secondary organic aerosols formed photochemically by gas-to-particle conversion processes during transport of polluted air masses across the South Coast Air Basin.

OTHER RESEARCH "SPIN-OFFS"

In addition to the work cited above directed to the achievement of the major research objectives of our NSF/RANN-supported program, several short-term projects were completed. These were scientifically intriguing

and technically useful in that they are directly applicable to current environmental problems and were readily carried out in our research facilities with the flexibility provided by the RANN program. Two examples of such projects follow.

High Resolution Infrared Absorptivities for Gaseous Chlorine Nitrate

The possible depletion of stratospheric ozone by fluorochlorocarbons has become a matter of considerable concern in recent years. Recently, it has been suggested[13] that the chemical models of the stratosphere be extended to incorporate the formation and destruction of chlorine nitrate ($ClONO_2$) via the reactions

$$ClO + NO_2 (+M) \rightarrow ClONO_2 (+M) \quad (1)$$

$$ClONO_2 + h\nu \rightarrow ClO + NO_2 \quad (2)$$

High resolution infrared absorptivities of $ClONO_2$ are required to quantitatively evaluate, by examination of infrared spectra obtained recently from balloon-borne spectrometers,[14] the possible presence of this compound in the stratosphere. Using the NSF/RANN-funded Michelson interferometer and data system, infrared absorptivities for four absorption bands of gaseous $ClONO_2$ were measured[15] at 0.0625 cm^{-1} spectral resolution for authentic samples of chlorine nitrate supplied by M. Molina and his co-workers. Figure 3 shows a plot of absolute absorptivity vs. frequency of the ν_2 fundamental of $ClONO_2$ which will be used in interpreting recent infrared spectra obtained during stratospheric flights.

Chemical Inhibition of Photochemical Smog: DEHA—Pros and Cons

Traditionally, control strategies for photochemical smog have focused almost exclusively on reducing emissions of reactive hydrocarbons and NO_x. However, the possibility of suppressing photochemical oxidant and aerosol formation by introducing chemicals into the atmosphere known to be free radical "traps," and thus which could act as inhibitors of smog formation, has been discussed for almost two decades.

Recently, it has been proposed that on the basis of "extrapolation from laboratory experiments," introduction of one such inhibitor, diethylhydroxylamine (DEHA), into urban air at concentrations of ~30-50 ppb, will effectively suppress photochemical smog formation.[16,17] Furthermore, it was stated that "this can be done for the entire United States at a cost of about $200 million per year compared to over $20 billion per year for automobile control device techniques."[16,17]

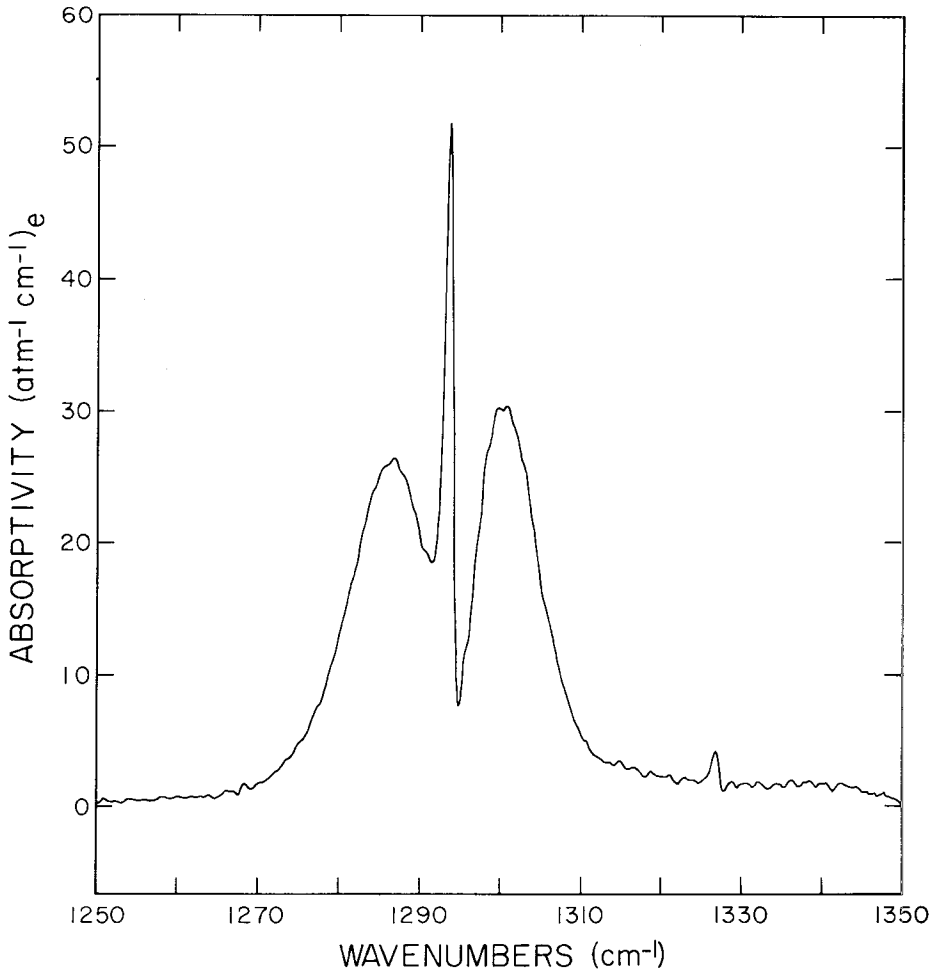


FIGURE 3— ν_2 fundamental of $ClONO_2$.

In addition, the scientists involved have proposed to officials of the city of Jerusalem, which has a photochemical smog problem, that actual "field tests" should be conducted there. These tests reportedly would involve the application of about 50 kg DEHA per km^2 into the city to produce an estimated concentration of ~50 ppb.[18]

If chemical inhibition by DEHA were shown to be both technically valid and free of health hazards, it might be an attractive air pollution control option. Thus its proposed use by Heicklen and co-workers has received widespread attention, not only by the scientific community,[18-20] but also by air pollution control officials and the general public.[21]

On the other hand, grave doubts have been expressed concerning possible health hazards associated with long-term human exposure to ppb-pphm levels of DEHA and its reaction products in photochemical smog.[1,18] Furthermore, the use of DEHA has also been seriously questioned on technical grounds. For example, to a significant extent the proposal is based on extrapolation of laboratory experiments for reactants in the millitorr pressure range to ambient atmospheres where concentrations are typically in the ppb-ppm range. Such extrapolation of laboratory results to real urban atmospheres is highly questionable, indeed "a delay in photochemical smog formation may merely transfer the problem downwind."[1]

Under our NSF/RANN program, we have tested the effectiveness of DEHA as an inhibitor of three characteristic symptoms of photochemical smog formation (i.e., oxidation of NO to NO_2, rate of formation and maximum levels of ozone and PAN, and production of secondary aerosol particles) under simulated atmospheric conditions in a dual outdoor Teflon environmental chamber.

Our results are interesting. Rather than acting as an inhibitor, we found that addition of 50 ppb, 100 ppb, or 200 ppb of DEHA to ambient air (with or without supplemental HC and NO_x) to our sunlight irradiated outdoor chamber resulted in a marked *increase* in the formation of ozone, PAN, light scattering particles, and rate of NO to NO_2 conversion. At 500 ppb DEHA acted as an inhibitor for approximately one hour; then the inhibition ceased and all of the above smog phenomena appeared, but at much faster rates and reaching substantially higher final levels in the DEHA "doped" side of the chamber vs. the non-DEHA side.

Typical results for 100 ppb of DEHA in Riverside ambient air are shown in Figure 4.[22] The results speak for themselves. Extrapolation from laboratory conditions to ambient systems can be fraught with uncertainties. Thus, experimental validation of proposed reaction schemes, insofar as possible under actual atmospheric conditions, is necessary.

ACKNOWLEDGMENTS

In addition to expressing my appreciation to NSF/RANN for support of the research described today, I should also like to thank my coinvestigators on the project, Drs. Daniel Grosjean, Arthur M. Winer, and George J. Doyle, as well as all other academic and nonacademic members of our research staff.

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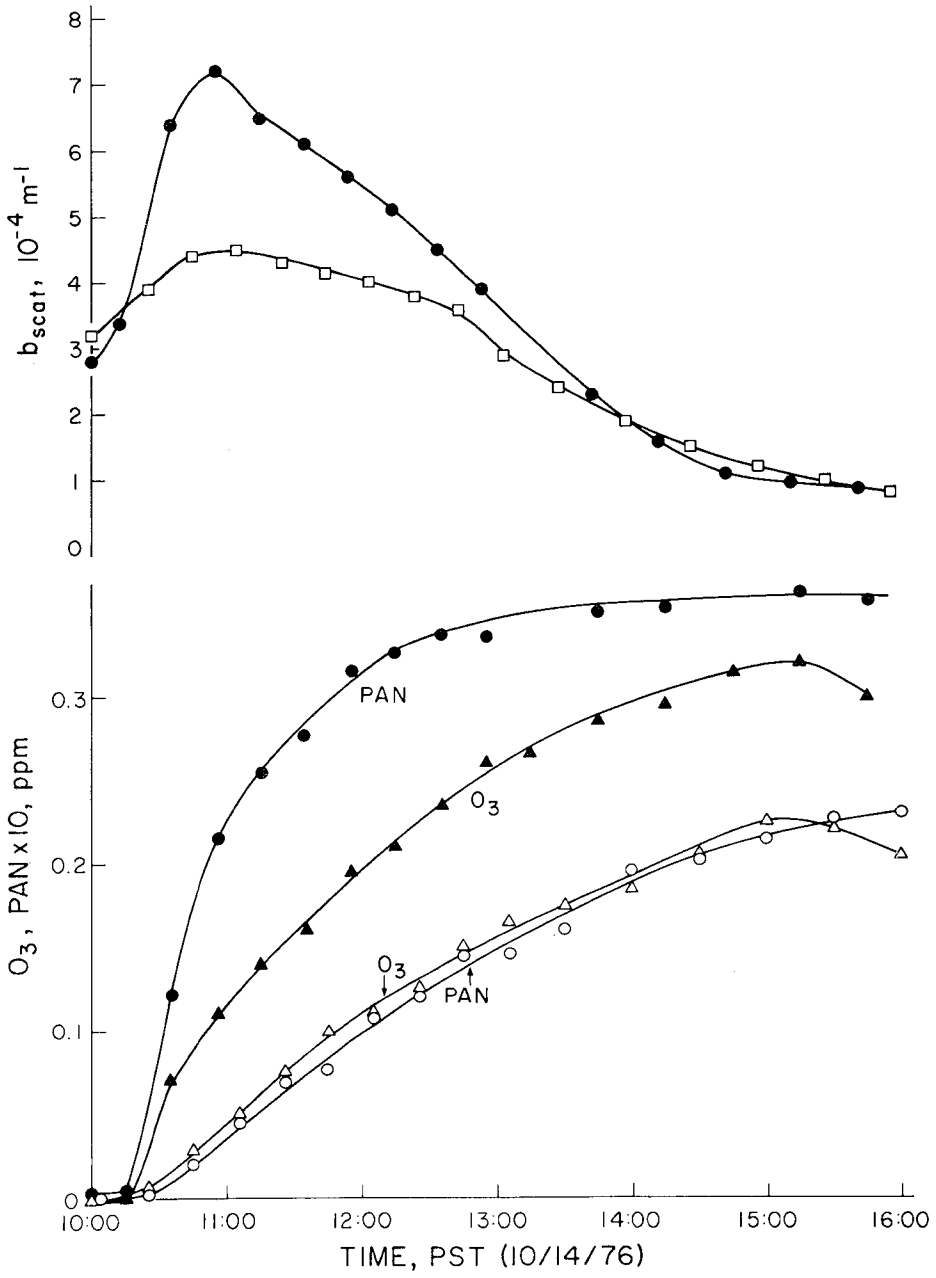

FIGURE 4—Concentration-time profiles for ozone (O_3), peroxyacetylnitrate (PAN), and aerosol light-scattering coefficient (b_{scat}) when irradiating ambient air without DEHA (open symbols) and with 0.1 ppm DEHA (filled symbols) in the SAPRC dual outdoor Teflon chamber. Initial ambient air pollutant levels were: NO: 69 ppb; NO_2: 58 ppb; total hydrocarbons: 3.73 ppm; non-methane hydrocarbons: 2.27 ppm; CO: 4.99 ppm; SO_2: 4.6 ppb, and PAN: 2.6 ppb.

N-Nitroso Derivatives of Pesticides and Other Chemicals of Commerce

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Because nitrosamines are known carcinogens, their presence in man's environment may be cause for concern. Many pesticide formulations contain amines and are therefore potential precursors of nitrosamines; the goal of the original RANN study was to assess the conversion of pesticides in soil and crops to nitrosamines. However, preliminary experiments showed that many pesticide formulations themselves contain the nitrosamines in extraordinarily large amounts. Even greater nitrosamine levels have been found in industrially important cutting fluids. The results suggest that little is known of the side reactions that occur when innocuous chemicals are mixed to make commercial formulations. If similar nitrosamine levels are found in formulations produced for other uses, then the finding may contribute significantly to an understanding of the ever-increasing U.S. cancer mortality rate. Cognizant federal agencies have been informed of the findings and their potential implications. Industry is striving to assess and limit the problem.

N-Nitroso compounds are of interest because, of about 130 which have been tested for carcinogenicity, approximately 100 have been shown to produce tumors in laboratory animals. So far, no animal species, including subhuman primates, have been found to be resistant to their carcinogenic assault.

N-Nitroso compounds are formed from the combination of amines (compounds containing nitrogen attached to at least one carbon atom) and nitrite or oxides of nitrogen. Many widely used pesticides are amines, and are potential precursors of N-nitrosamines. Indeed, several pesticides have been shown to be readily convertible into their respective N-nitroso derivatives. The goal of our RANN research program, therefore, was to search soil, run-off water, and agricultural crops for N-nitroso pesticide derivatives which could have been formed by nitrosation with soil nitrite. The problem of N-nitroso derivatives is important because, if relatively innocuous pesticide residues are converted into carcinogenic compounds which make their way into the human food chain, then the widespread use of pesticides would need reassessment in terms of increasing the world's food production capacity versus the widespread introduction of potent carcinogens and the consequent lowering of the average human lifespan.

The potential N-nitrosamine hazard from pesticides was first brought to the attention of two appropriate federal agencies. Because of the diverse nature of the problem and because the problem cuts across traditional administrative and scientific boundaries, the two agencies were not able to support the research. One of the scientists to whom we spoke was Dr. Page Nicholson of EPA in Athens, Georgia, who suggested that the agency best suited to support the multidisciplinary project was the National Science Foundation's RANN program.

The project was initiated in January 1976, and the first field samples were collected during the spring 1976 planting season. Some of the fields which we studied were in the Sacramento Valley in California, during the application of the herbicide Treflan. Treflan is a relatively volatile herbicide, and we were planning to study possible air nitrosation as well. When the field samples were analyzed, we did not find nitrosamines in the air, the soil, or in the run-off water, but we did find dipropylnitrosamine in the herbicide formulation itself. The concentration of the dipropylnitrosamine contamination was about 200,000 ppb (μg/kg), which was at the time the highest

nitrosamine contamination yet reported. Encouraged by this result, we screened six herbicide formulations which contained dimethylamine salts, and we found dimethylnitrosamine to be present in four of the six which we tested. One formulation which is used as a nonselective herbicide by utility companies was found to contain 640,000 ppb concentration of dimethylnitrosamine. The nitrosamine data on pesticide formulations were confirmed in our own laboratory using parallel liquid chromatography and gas chromatography techniques, interfaced to a nitrosamine-specific detector, called a Thermal Energy Analyzer (TEA). Because of the importance of the finding, the results were confirmed by independent laboratories prior to publication. The collaborators were Klaus Biemann at the Massachusetts Institute of Technology, Steven Tannenbaum at the Massachusetts Insitute of Technology, Edo Pellizzari of Research Triangle Institute, N.C., and Nisu Sen of the Canadian Bureau of Foods. Most of the findings were subsequently confirmed by the manufacturers themselves.

The nitrosamine contaminants in the amine salt herbicides resulted from the nitrosation of the amine by sodium nitrite, the sodium nitrite being added to the final commercial package as a rust inhibitor. Nitrite-amine formulations are not unique to herbicides. One such product is the synthetic cutting fluids which contain up to 45 percent triethanolamine and 18 percent sodium nitrite. Because of our experience with the nitrite-herbicide formulations, we tested seven commercial cutting fluids for N-nitrosodiethanolamine. All synthetic cutting fluids which we tested were found to contain N-nitrosodiethanolamine at concentrations varying from 200,000 ppb (0.02 percent) up to 30,000,000 ppb (3 percent)! This result was also confirmed in an independent laboratory prior to publication. Daily exposure to percentage concentrations of a known carcinogen is cause for concern to the 750,000 American workers who use cutting fluids in the course of their work, especially as cutting fluid users have already been shown to be more susceptible to certain types of cancer than the rest of the population.

Because of the discovery of nitrosamines in the pesticide formulations themselves, the emphasis of the research has shifted to include other commercial products which might have similar problems. The original goal of assessing the importance of N-nitroso pesticide derivatives in the environment is continuing, with additional effort now being expended in capitalizing on a new perspective and a new understanding of how man may be inadvertently exposing himself to nitrosamines, namely exposure via the chemical formulations of commerce.

One approach to assessing and limiting man's exposure to the carcinogenic nitrosamines would be to test every chemical formulation which is used today. With between 700 and 1,000 new chemicals entering commercial production each year, the task is clearly impractical. An alternative approach is to use the new perspective to pinpoint groups of chemicals which may be suspect. Two such groups can already be identified. First, the widespread use of nitrite rust inhibitors must be reevaluated, particularly when amines are present as well. Second, the contamination of Treflan apparently arose during synthesis from the introduction of a nitrosating agent prior to the addition of an amine. All products whose synthesis involves nitrosating agents and amines must also be suspect and should be tested for possible nitrosamine contamination.

Because population groups which had been exposed to nitrosamines had not been previously identified, no information is currently available concerning the possible carcinogenic action of nitrosamines on man. As a direct result of this study, pesticide applicators and cutting fluid users have the dubious distinction of being the first such population groups to be associated with nitrosamine exposure. Two groups of researchers have already begun to initiate epidemiological studies on these worker groups.

The Environmental Protection Agency, the National Institute for Occupational Safety and Health, the National Cancer Institute, and other cognizant agencies have been informed of the findings. The companies whose products are involved have also been notified. As a result of these disclosures, industry and the federal agencies are striving to understand the scope of the problem and to limit the exposure. As a direct result of this study the Environmental Protection Agency has begun to screen pesticides for N-nitrosamine impurities. One company has withdrawn some of their pesticide products which are packaged with nitrite rust inhibitors. The National Institute of Occupational Safety and Health has issued an emergency bulletin, informing machine shops and organized labor of the potential exposure to nitrosamines from cutting fluids.

Irrigation for Minimal Nitrate Pollution

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The results presented are part of the RANN-supported project, "Nitrate in Effluents from Irrigated Lands," which has the objective of developing a capability to predict amounts of nitrate in waters that percolate through irrigated soils. This project was a response to conflicts between societal needs for food and fiber that demand increasing amounts of nitrogen in soils and environmental considerations that call for lesser amounts in waters. A capability to predict nitrate leakage would favor rational decisions on alternative solutions. Field research has demonstrated that water management which determines the volume of water percolating through the soil-plant system is a dominant factor in controlling nitrate leakage and that the mass of nitrate might be more reliable than concentration as an estimate of pollution. Control strategies based on irrigation water management to reduce effluent volumes would be helpful in reducing leakage and might be more effective than strategies based on control of nitrogen inputs.

This paper discusses results from a RANN project entitled "Nitrate in Effluents from Irrigated Lands," which was initiated in 1972 and will terminate in 1978. The project is jointly financed by RANN/NSF and the University of California through the Kearney Foundation of Soil Science and the Agricultural Experiment Station. Three campuses, several field stations, and a large number of farmers' fields have been and are involved in the research.

OBJECTIVE

The overall objective of this project is to develop a capability to predict the amounts and concentrations of nitrate in the water that percolates through the root zone of soils of irrigated lands. The completion of this objective depends on our understanding of what happens to nitrogen after it is added to soil, including removal in harvested crops, accumulation in soil organic matter, denitrification, and leaching beyond the root system. Thus, specific subprojects deal with (1) nitrogen transformations with special emphasis on denitrification; (2) field trials using stable isotopes of nitrogen to trace nitrogen through the soil-plant-water system; (3) relationships among nitrate in tile-line effluents, nitrogen inputs, soil properties, and water management; (4) the same relationships for freely drained fields where tile-lines are not necessary; (5) soil profile characteristics in relation to nitrate leakage from the root zone; and (6) the development of models for the behavior of water and nitrogen in irrigated soils.

ORIGIN AND ORGANIZATION

This project was developed in response to conflicts between societal needs for food and fiber productions that require increased levels of plant available mineral nitrogen in soils and environmental and preservational considerations that call for lesser amounts of nitrate in waters. This conflict has not decreased since the project was initiated; in fact, data collected have shown that these conflicts are most intense in irrigated basins where groundwater is used for agricultural, municipal, and industrial supplies.

After the project was under way, a potentially new conflict between increased use of nitrogen fertilizers and environmental concerns developed. The possibility was brought to the attention of the public that increased nitrogen fixation to meet the needs of an expanding global

population will increase the production of nitrous oxide which will diffuse to the stratosphere where it will destroy ozone and let more ultraviolet light impinge upon the earth's surface, with adverse effects on human health and biological activity. Because nitrous oxide is one of the products of denitrification in soils and waters, the project research on denitrification has become even more relevant.

Once the need for research on the leakage of nitrate from irrigated soils was recognized and RANN personnel had agreed to receive and consider a proposal, six researchers representing the Berkeley, Davis, and Riverside campuses, and specialists of plant physiology, soil microbiology, soil biochemistry, soil physics, and soil chemistry met one day per month for several months to outline the project. When the project proposal was written in 1971, five more researchers were added to the project. The final project proposal listed 26 people, 11 research leaders, and 15 advisors including two ARS-USDA researchers, and several extension specialists of the Cooperative Extension Service of the University of California who provide excellent contact with user groups.

The project was organized into subprojects or activities that were managed by research leaders from university campuses. Meetings of research leaders and advisors are held quarterly and a technical conference is held each year to keep all personnel informed of progress and to promote cooperation among project activities.

RESEARCH RESULTS

Data from field research have shown that the volume of effluent that leaves the root zone of irrigated soils is one of the dominant factors in controlling the quantity of nitrate leakage. This conclusion comes from field trials with isotopes, measurements of nitrate in tile line drainage, and in the percolating water in the unsaturated zone in freely drained fields, soil morphology studies, and from a field trial with animal manures as the source of nitrogen inputs.

A study of nearly two dozen tile-drained irrigated fields showed that nitrate concentrations in effluents were not correlated with fertilizer nitrogen inputs, and that the amounts of nitrate leached were correlated with nitrogen inputs, but were more highly correlated with effluent volume and soil profile characteristics. Soil profiles exerted control through their direct effects on drainage volume and their indirect effects on denitrification.

A study of nearly 50 free drainage sites suggests that the one factor that might most effectively reduce leakage losses is water management to produce small effluent volumes. Preliminary data from the Davis RANN site using stable nitrogen isotopes show that the volume of percolating water is a dominant controlling factor in leakage of nitrate for any given fertilizer nitrogen rate. Data from a four-year field trial with dairy and feedlot manure demonstrated reduced nitrate leakage by reducing the drainage volume from 50 surface cm per year to 25 surface cm per year and without a reduction in crop yields.

If the quantity of nitrate that is subject to leaching in a given soil were a constant, the quantity leached when water moves through the soil would be independent of the volume of effluent. Also, the concentration of nitrate in the effluent would be inversely proportional to the effluent volume. That is, doubling the volume would decrease the concentration to one-half its original value. But, the amount of nitrate that can be leached is not a constant and increases as the volume of effluent increases. To produce high yields of crops a soil must have a supply of plant available inorganic nitrogen during the crop growth period. The consequence of this available nitrogen is that anytime water escapes below the root zone, some nitrate moves with it, and the nitrate leached increases as the amount of water moving through the root zone increases.

Extrapolation of the relationship between nitrate leakage and drainage volume would suggest that irrigation for zero drainage would minimize nitrate pollution of ground and surface waters. However, reducing drainage to zero would soon cause salt accumulation to the point where reduced yields would make irrigation agriculture economically impossible. Recognizing that some leaching of water through irrigated lands is a necessity and that large leaching volumes cause large leakage of nitrate, water management techniques must be developed to reduce effluent volumes to a minimum that can still maintain top yields of crops and to provide nitrogen and water management so that needed leaching occurs during periods of minimum nitrate in the soil root zone.

APPLICATION

Extension specialists of the Cooperative Extension Service of the University of California have conducted RANN training sessions with county extension personnel in all regions of California to inform them of the results of this nitrate project. These sessions have served, and sessions planned for the next two years will serve, to get information to farmers and to personnel of irrigation and drainage districts and of local government agencies. Two conferences have been held for the presentation of results and concepts to people from government agencies at the local, regional, state, and federal levels.

One concept that has developed from our research is that criteria for water pollution from nitrates from irrigated agriculture should be based on mass emissions of nitrate and not on concentrations of nitrate in effluent waters. Where the volume of effluent is relatively constant, such as with municipal and industrial wastewaters, concentrations provide indexes to mass emissions, i.e., decreasing the concentration by 50 percent reduces mass emission by 50 percent. In irrigated agriculture the effluent volume is not constant from field to field, from basin to basin, or from year to year. The disadvantage of concentration criteria is that it would favor use of larger volumes of water to dilute the nitrate which would decrease irrigation water use efficiency, promote leaching of nitrate, and thus, decrease nitrogen use efficiency. That is, more water and nitrogen would be used per unit of harvested product. Also, the quality of receiving waters might be improved in most cases by discharge of smaller masses of nitrate even though the concentration

in the effluent from the land might be higher with smaller effluent volumes.

Irrigation control technologies being developed for minimum leaching for salinity control will also serve to conserve nitrogen and reduce leakage of nitrate into surface and ground waters. These technologies usually require increased capital investments for equipment such as sprinkler systems and increased consumption of energy to provide water under pressure. The gains in water and nitrogen use efficiencies will need to be balanced against capital and energy costs to judge the total advantages to society. On the other hand, some reductions in drainage volumes can be attained by better management of water using gravity systems merely by better scheduling of water and control of amounts used during each irrigation.

Integrating Research and Scientific Resources into Public Policy: The Case of Polybrominated Biphenyls (PBB) in Michigan

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This paper discusses the role of scientific data and scientific committees in the debates over safe limits for the environmental contaminant PBB. In July 1973, fire retardant containing polybrominated biphenyls (PBB) was accidentally substituted for magnesium oxide in a shipment of cattle feed sold in Michigan. This accident introduced the highly toxic PBB contaminant into the environment. Soon after, indications of some form of toxicity were noted in cattle, and studies identified the contaminant as PBB. The U.S. Food and Drug Administration then established a limit of 1 part per million on a fat basis for the sale of milk, meat products, and meat. As more sensitive analytical capabilities were developed, this limit was reduced to 300 parts per billion. State health authorities could find no correlation between PBB levels in this range in animals and man and toxicity, but research reported in scientific literature linked PBB to liver cancer in rats and teratogenic effects in animals. These apparently conflicting results created uncertainty in the minds of the citizens and the Governor. The Governor convened a special scientific panel to assess all information on PBB effects on human health, to advise him on the acceptability of existing PBB limits on the sale of meat, milk, and poultry, and to recommend new limits if the existing limits were too high. The panel recommended lower levels than FDA standards for PBB concentration. The State Department of Agriculture disagreed, stating that the economic damage attending lower levels was not justified by the studies reviewed by the scientific panel. The Governor then sought legislation to establish new levels based on the scientific panel recommendation.

In September 1973, a herd of cattle on a farm near Battle Creek, Michigan, inexplicably began to exhibit symptoms of toxicity. The first symptoms were a loss in appetite and a dramatic reduction in milk production, followed in approximately two months by abnormal hoof growth, changes in skin, abnormally high rates of abortion, and a reluctance to breed.

Following a series of studies conducted by the Michigan Department of Agriculture, it was determined that the toxicity was being transmitted in cattle feed purchased from the Farm Bureau Services. The nature of the toxic agent, however, could not be identified through those studies.

In January 1974, the use of gas-liquid chromatography at the National Animal Disease Center identified the existence of an unknown chemical substance in the feed. Finally, in April 1974, nine months after the feed was first used, the substance was identified by the National Pesticide Degradation Laboratory as polybrominated biphenyl (PBB).

During these nine months, Farm Bureau Services continued to market their feed throughout Michigan, and this highly toxic nondegradable chemical was introduced into the Michigan environment.

The United States Food and Drug Administration acted immediately after the toxic agent was identified to establish a limit of one part per million (on a fat basis) in milk, milk products, and meat for human consumption.

This guideline was based on the most sensitive analytic capability then available. In November 1974, the guidelines were reduced to 300 parts per billion on the basis of newly developed data indicating similar toxic effects from PBB and PCB (polychlorinated biphenyl) and the availability of more sensitive analytical capabilities.

Until this point, there was no significant role for Governor Milliken in this issue. The FDA was responsible for establishing the limits for human consumption, and the USDA and Michigan Department of Agriculture were responsible for removing products above these limits from the market. However, the widespread distribution of PBB throughout Michigan was becoming an issue of public concern.

Farmers whose herds exhibited symptoms of toxicity but whose herds tested below the guidelines of 300 ppb were faced with a dilemma. They could either market

food products which they believed to be contaminated or destroy their herds without benefit of insurance since their herds were not officially condemned.

The consuming public had to choose between purchasing meat, milk, and poultry that might contain low levels of PBB or to stop consuming these products. The Farm Bureau Services and their insurers were interested in maintaining the highest level consistent with public health as lower limits increased their liability by condemning additional herds of cattle.

Scientists disagreed on the facts and on the most appropriate course of action. Research initiated and sponsored by the U.S. Department of Agriculture failed to establish a direct relationship between PBB levels in fat tissues or blood at these low levels and symptoms of toxicity. Based on these results, they could not justify lowering the acceptable market level of PBB below 300 ppb.

In late 1975 and early 1976, reports of experiments relating PBB to liver cancer and other teratogenic effects appeared in scientific literature. While these experiments were conducted with relatively high levels of PBB, they added to the concern of the public.

Governor Milliken, confronted with these apparently conflicting opinions, sought additional scientific advice, and created a PBB Scientific Advisory Panel in April 1976.

The duties of the panel included (1) a review of all scientific data available on PBB, (2) recommendations on PBB limits for meat, milk, poultry, and eggs. Specifically, are the present limits safe, and if not, what level should be adopted? (3) Are there long-term human health risks from ingestion of PBB, and how should these factors relate to the limits?

The advisory panel concluded that no specific disease or symptomatology in animals or man can presently be associated with exposure to low levels of PBB. High levels of PBB, however, did produce carcinogenicity and death.

There were no definitive studies on the long-term effects of exposure to PBB, and the panel concluded there was significant danger based primarily on PCB research. Here, too, low levels of exposure were not directly related to identifiable toxicity effects, while high levels were clearly teratogenic.

Concurrently with these activities, the Michigan Department of Agriculture had developed and was using laboratory procedures capable of detecting levels as low as 5 ppb in meat and eggs, and 1 ppb in milk.

The dilemma faced by the governor now had to be addressed by the scientific panel. That is, there was no direct evidence that levels as high as 300 ppb represented a health hazard to society. Yet, the capability to detect lower levels existed, and there was public pressure to establish limits at the lowest detectable level, preferably zero, if you could measure that low.

The panel chose the latter course of action, recommending the levels be established at the lowest detectable level (5 ppb in meat and eggs, and 1 ppb in milk). They further recommended that as techniques are developed which permit reliable detection at lower levels, that these limits be revised to reflect these capabilities. Consistent with scientific practice, they also recommended that the state fund further studies of the long-term effects of low-level exposure.

The panel conclusions were used by proponents of both sides of the issue. Those that favored retaining the present level pointed to the conclusion that there was no evidence of adverse health effects at these limits, and those that favored lowering the limit pointed to the recommendation that the limits be set at the lowest detectable level.

While it is not my intent to chastise the scientific community, it is clear this report did little to help solve the governor's dilemma. No matter which decision he made, he was vulnerable to criticism from the opponents of that position, based on the report and recommendations of his own advisory panel.

In my position as science advisor to the governor, I often encounter the position that the political decision-making process does not rely heavily enough on science input. And, prior to assuming this role, I was an advocate of that same position. While I have not changed my view completely, I have developed a better understanding of some of the reasons why this is true.

In the political world in general, and in this case in particular, a decision had to be made. Either the limits would remain at 300 ppb or they would be lowered to 5 ppb. It is not adequate to document that there are arguments on both sides and return the problem to the governor. If there were not arguments on both sides, the panel would not have been formed in the first place.

I personally favor the position that the scientific community, if it is to receive adequate consideration in the public decision-making process, must adopt more of an advocacy position. This does not mean we fail to present all the facts as we know them, or that we fail to present unanswered questions. Rather, it means that we should take positions and present to the governor, or other decision-makers, the best set of arguments for adopting that position. This may only mean a change of emphasis, not a change in content.

This approach does not guarantee the position being advocated will always be adopted, but I feel it will improve its probability. Other segments of society, including the public at large, do not hesitate to take an advocacy position based on far less information and far less training than the scientists.

Another example will help to make my point. In Michigan we are being asked to approve the exploration of a specific site as a possible nuclear waste repository. The public, in a recent referendum, voted nine to one against allowing the site even to be considered. A scientific task force, appointed by the governor, addressed this issue and reached the conclusion that there is no technical basis for prohibiting the exploration in Michigan. We are still debating the form of our response, the question being whether to recommend that the exploration be approved or to simply state that there is no scientific basis for not exploring the site. I contend that to adopt the second approach fails to meet our responsibilities to the governor.

The PBB issue in Michigan is still not resolved. The governor chose to adopt the recommendation that the limits be set at the lowest detectable level, but the Michigan Department of Agriculture and the FDA did not concur and they retained the higher level.

There is now evidence that traces of PBB are present in the milk of nursing mothers. The Department of Public Health is considering the question of acceptable limits to recommend as a basis for nursing. The U.S. Department of Health, Education, and Welfare has formed a scientific task force to review health effects of exposure to PBB, and the controversy continues.

This is a tough issue, as are many of the science-related issues facing society, and I am hopeful we will continue to develop the mechanisms through which scientific thought and scientific data enter the decision-making process. Clearly, the efforts of this RANN program are oriented to these ends and will have a tremendous input to future decisions.

Environmental Contaminants: Discussion

QUESTION: I have a question for Dr. Fine. You identified the two groups that were exposed to nitrosamines and said that you were looking for a correlation between their exposure and the incidence of cancer. Are there any results on those data? I mean, are you also looking back in the past records of people who have been working with this material over a long period of time?

DR. FINE: We are not doing the epidemiology. I know two groups of workers who have started to to this, one at NIOSH and the other at Mt. Sinai Hospital in New York, and they are going to go back and look at the past history and presumably the future history as well. But so far there have been no results.

QUESTION: What kind of a disposal problem did you have with your PBB contaminated animals?

DR. TAYLOR: Our problem was how to get rid of them. Our solution was to bury them. They are buried in clay at a couple of sites in Michigan now, aggregated, killed, and buried.

QUESTION: Would you give me the name of the geologist who did your work?

DR. TAYLOR: It was the office of the state geologist; O'Nell is his name.

QUESTION: Dr. Fine, you said that it was too difficult for the EPA to try to test all of these chemicals, but under this new toxic chemical law, isn't the EPA entrusted with monitoring all chemicals and especially all new chemicals?

DR. FINE: I would rather not comment directly on the legislative aspects, but just the purely practical aspects. There are, in herbicides alone, I believe, 40,000 formulations licensed in the United States. If you go to other chemicals of commerce, their number may be of an equivalent size. There are approximately 700 new chemicals coming into use every year. To test each one of these in the formulation that is actually used is a task which would consume most of the chemical resources of the United States, and it is just not practical. There has to be some guiding principle to pinpoint the main areas and then let the manufacturers, once they are aware of the problems in their industry, correct the problems.

QUESTION: You mentioned the problem with the machinist cutting oil giving an environmental problem internally in the machine shops. Have you ever looked into the area of the vaporization of the resin from solder cores and so forth? There must be a half a million people who are soldering in closed rooms in the United States.

DR. FINE: We haven't. I am not aware what the formulation of the resin is. If it is an amine-type resin, then it would be very interesting, indeed. I don't know that the formulation is.

QUESTION: In a paper this morning on the disinfection of sludge by high energy electrons, I mentioned that PCB, in a preliminary model experiment, was broken up by two megarads, that we were proceeding down to the disinfection dose of 400,000 rads. Would this possibly be of interest to the people in Michigan in connection with PBB and PCB?

DR. TAYLOR: The answer is yes. I was in contact with the Sandia Labs just last week, as a matter of fact, and they had also been doing some PCB degradation with cesium-137 which is what I believe they were using, and so we are interested in pursuing that. We have two problems, perhaps. If we get the nuclear waste, then we can bury them together and we will solve all of our problems, perhaps.

QUESTION: My question is for Dave Fine. Would hydroxyl amine in the atmosphere make nitrosamine compounds?

DR. FINE: We would think so, from the chemistry. It's a compound with two methyl groups attached to a nitrogen and OH. The only difference from a nitrosamine is that there is OH there instead of NO, and the supposed chemistry is to mop up the NO, and one would expect, therefore, the nitrosamine.

QUESTION: Dr. Fine, could you elaborate a little bit more on the herbicide which you investigated for management of utility rights of way?

DR. FINE: This was 2,3,6-trichlorobenzoic acid, formulated as the dimenthylamine salt. This is a nonselective herbicide which has been used for the last 10 or 15 years, and kills everything, grass, trees. It is used for clearing a patio in the home, clearing a driveway, or for a utility, telephone, or power utility, clearing the right of way for the cables. It is spread on the ground. It is used as a spray, and it is pumped out as a fine aerosol spray.

Roundtable Paper

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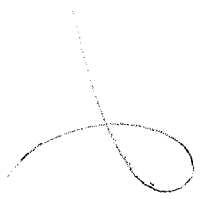

Emissions from Major Air Pollution Sources and Their Atmospheric Interactions

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We have measured the concentrations of gases and the size distributions and compositions of particles emitted from major air pollution sources of types that are normally found in U.S. metropolitan areas (especially in the East): coal- and oil-fired power plants, municipal incinerators, and motor vehicles. From flights through plumes with an instrumented aircraft, we find that, under conditions of high temperature, sunlight intensity, and humidity, gases from power plants can react to form large quantities of ozone many miles downwind from the plant. Although municipal incinerators release little particulate mass, they can account for much of the zinc, cadmium, antimony and, possibly, silver, and tin in the atmospheres of many cities. Preliminary studies indicate that coal-fired power plants release far greater quantities of carcinogenic polynuclear aromatic hydrocarbons than previously thought.

Prior to the start of this project, the concentrations of pollutant gases and some toxic elements on particles in urban atmospheres were moderately well known. However, before regulatory agencies can devise optimum strategies for the control of harmful substances, they will need to know the major sources of these pollutants, both those emitted directly from the sources and those secondary pollutants (e.g., ozone) that are formed by reactions of primary pollutants after release into the atmosphere. Our group at Maryland was formed to investigate the emissions from major sources and their interactions in the atmosphere. The group consisted of five faculty members in chemistry (D.D. Davis, T. C. O'Haver, S. W. Staley, W. H. Zoller, and myself) and two in meteorology (H. E. Landsberg and G. W. Israel). Our objective was the measurement of concentrations of gases and the size distributions and compositions of particles emitted from major air pollution sources of types that are normally found in U.S. metropolitan areas: coal and oil-fired power plants, municipal incinerators, motor vehicles, continental background, and other minor sources. Furthermore, we have investigated the behavior and reactions of these species after release. At the start of the present project year, Profs. Davis and Israel left the university and the project, and another chemist, Dr. Paul Mazzocchi, joined the project team to study organic compounds in the atmosphere that may be involved in the production of ozone in plumes from point sources.

GAS-PHASE INTERACTIONS IN PLUMES

Probably the most important air pollution problem from a national point of view is the question of how sulfur dioxide (SO_2) is converted to particulate sulfates and sulfuric acid. Some of our work has been directed toward that question (e.g., laboratory measurements of the rates of gas-phase reactions involving SO_2), but we have directed our major gas-phase efforts on the sources and production of ozone (O_3). Here in the Washington, D.C., metropolitan area, most of our days of high Air Quality Index (AQI) occur during warm periods of the summer and early fall. The high AQIs are caused mainly by high concentrations of photochemical oxidants of which ozone is the major component. This is a similar, but less intense and frequent condition to that typically existing in Los Angeles "smog."

It is now well known that ozone is a long-range problem. Under appropriate conditions, pollutants

*Presenter

released in one area may react over many hours to produce high ozone concentrations 100 km or more downwind. For example, when the wind is from south to southwest, pollutants from Richmond, Virginia, may produce high O_3 in Washington, which adds more pollutants to give higher levels by the time air reaches Baltimore, and so forth up the East Coast. The O_3 standard of 80 parts per billion (ppb) is frequently exceeded in rural areas hundreds of miles downwind from major sources. Thus, if the AQI and the O_3 standards are meaningful quantities in terms of the impact on human health, animals, and vegetation, it is essential that we determine the sources of O_3.

Based on the extreme degree of photochemical air pollution in Los Angeles, air pollution authorities have generally considered automobiles to be the major source of O_3 and other photochemical oxidants. It is well established that hydrocarbons and nitrogen oxides (nitric oxide, NO, and nitrogen dioxide, NO_2, abbreviated collectively as NO_x) in auto exhaust can react in the presence of intense sunlight to yield large quantities of O_3 and other oxidants. The role of point sources such as power plants has largely been ignored. Most state and local strategies for dealing with episodes of high ozone place the highest priority on reduction of traffic during these periods. While this measure probably helps, it cannot be completely successful unless cities extending far upwind also initiate stringent control measures.

To investigate ozone production by point sources, Prof. Davis and his students equipped a light, fixed-wing airplane with instruments that measure concentrations of various pollutants—ozone, SO_2, NO, and NO_2, etc. Dozens of flights were made in which concentrations of these species were measured by traverses of plumes from large sources at many distances downwind from the stacks as well as near major highways, downwind from cities, and in general background air. Plumes from large power plants can often be followed for 60 km or more by observing the high SO_2 concentrations in them.

Davis et al. observed some very interesting effects involving ozone. During warm weather, O_3 concentrations are typically 60 ppb in background air. But in a fossil-fuel power plant plume within a few km downwind of the stack, the O_3 concentration drops nearly to zero. This is caused by the very fast reaction of NO (produced from N_2 and O_2 of air in all high temperature combustion sources) with O_3:

$$NO + O_3 \rightarrow NO_2 + O_2$$

This reaction is well understood. However, it was surprising to find that, under some conditions, the O_3 concentration builds up to levels above that of background air at distances usually about 40 km or more downwind, *indicating that power plants can be net sources of ozone.* When ambient air has 60 ppb O_3 concentrations, the ozone "bulge" in the plume may reach 90 ppb. At those great distances from the source, the plume may have a width of 10 km or more, so if the plume descends to ground level, it can cover an entire city with air in which the O_3 concentration is above the 80 ppb standard. Any O_3 generated locally by auto exhaust would push the concentration even higher. Thus, individual point sources upwind from a city can cause excessive photochemical oxidant levels in the city under certain meteorological conditions.

At present we do not know the exact mechanism by which the O_3 is produced. We know that some conditions are necessary: temperatures above 80°F, high absolute humidity, and intense sunlight. We suspect that the ozone bulge is produced by mechanisms similar to those that produce Los Angeles smog, i.e., reactions between NO of the plume and hydrocarbons of air mixed into the plume, in the presence of sunlight. Since power plant plumes usually contain very little hydrocarbon, it is necessary that it be supplied by air that mixes with the plume.

If the above general explanation is correct, we still need to know the sources of hydrocarbons. In some instances, the source is probably auto exhaust, e.g., when a power plant plume mixes with air over a heavily traveled highway such as I-95 south of Washington. In at least one case we observed an enormous bulge that appeared to involve the plume from a cellophane plant near Fredericksburg, Virginia, that contained large amounts of organic solvent vapors. Two pieces of evidence suggest that some local, natural hydrocarbon vapors, such as terpenes released by softwood forests, may be important: (1) Little, if any, evidence has been obtained for O_3 bulges in similar experiments conducted at power plants in the West, Southwest, and near St. Louis, and (2) we have observed substantial O_3 bulges from a small, coal-fired plant located in rural Virginia in the midst of woods, far from major highways, cities, or point sources.

To clarify the issue, Professor Mazzocchi and Mr. William Keifer are now developing methods for measurement of organic compounds. We plan to measure concentrations of various organic components in ambient air near plumes that produce O_3 bulges.

ATMOSPHERIC PARTICULATE PROBLEMS

Trace (and Toxic) Elements on Particles

To determine the sources of toxic elements on particles suspended in ambient urban air, Profs. Zoller and Gordon and co-workers collected particles from the stacks of coal- and oil-fired plants and municipal incinerators, from the Baltimore Harbor Tunnel, and from ambient air in and around Washington. These particles were analyzed for 30 or more elements by highly sensitive nuclear methods of analysis and atomic absorption spectrometry. Results of these studies can be summarized as follows:

- Although coal-fired plants release large masses of particulate material, coal combustion is not the major source of most toxic elements, the main exceptions being arsenic and selenium as well as mercury vapor. Furthermore, most particle mass from coal combustion is on fairly large and insoluble particles. Both of these properties tend to reduce the health effects of particles from coal combustion
- Oil combustion accounts for most of the vanadium and nickel on urban particles. These and most other elements from oil-fired plants are concentrated on small, respirable particles.

- Motor vehicles are the major source of lead, bromine, chlorine, and, possibly, barium on urban particles, and the particles are of respirable size.

- Municipal incinerators contribute very small amounts of particle mass to urban atmospheres, but the particles are so rich in trace elements that refuse incineration can account for most of the atmospheric zinc, antimony, cadmium, and, possibly, tin and silver in many cities. These elements are predominantly attached to respirable, soluble particles, both of which enhance public health problems. These findings raise some serious questions that must be answered before the use of urban refuse in fossil-fueled power plants becomes widespread.

Carcinogenic Organic Compounds on Particles from Coal-Fired Plants

Prof. Staley and his co-workers have developed a highly sensitive method for measuring atmospheric concentrations of the class of compounds called "polynuclear aromatic hydrocarbons" (PAHs), some of which are known to be carcinogenic, including benzo(a)pyrene. From older measurements, air pollution authorities had estimated that all coal-fired power plants in the U.S. together released only about one ton of benzo(a)pyrene per year. However, Staley et al. recently measured concentrations of PAHs in material collected with an airplane from the plume of a large coal-fired plant in New Mexico. By measuring SO_2 concentrations in the plume during PAH collection and by knowing the sulfur content of the coal being burned, it was possible to estimate the amount of PAH compounds released per megawatt-hour of electricity produced.

From the results of this experiment, Staley estimates that this single plant releases an amount of benzo(a)pyrene comparable with that previously estimated for all coal-fired plants in the United States. We feel that this discrepancy arose in the following way: Most previous estimates of benzo(a)pyrene release were made by analysis of *particles* collected in the stacks of power plants. But many PAHs are so volatile that they are mainly present in the gas-phase at the high temperatures of power plant stacks. Only by collecting particles and vapor from the stack or by collecting particles from the plumes after mixing with cool, ambient air can one obtain a meaningful estimate of the release of these compounds.

The finding of greater releases of PAH compounds is not necessarily reason for alarm. Although the findings indicate a need for careful follow-up studies, we do not yet know if the PAH compounds survive for a long time in the atmosphere. This question is now under investigation

APPLICATION OF RESULTS

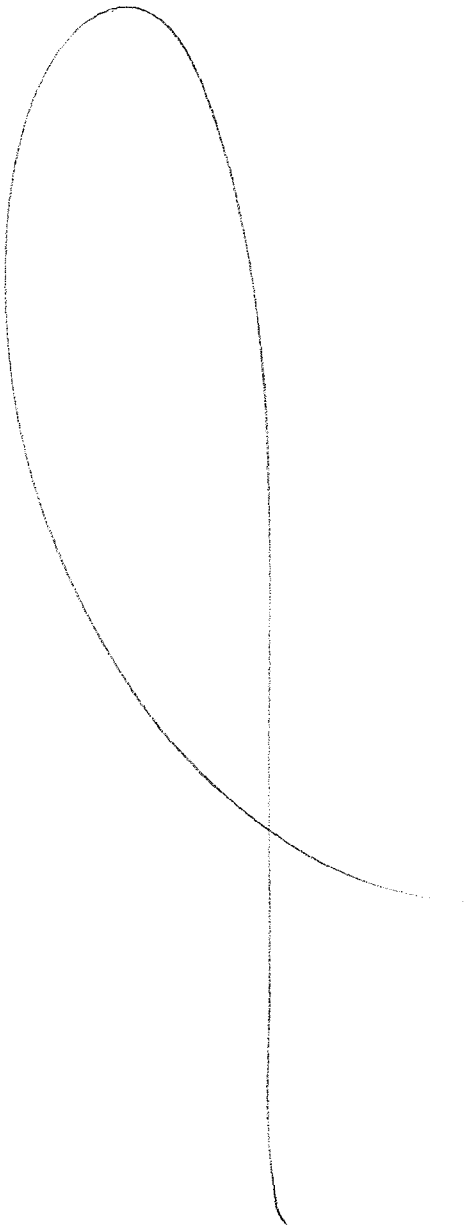
Our results will be of most immediate applicability by atmospheric regulatory authorities within EPA and state and local agencies. Already we know that ozone concentrations frequently exceed standards. By the end of our project, we hope to have identified all of the factors involved in ozone production well enough that optimum control strategies can be devised by the regulatory authorities. In the cases of most of the other pollutants (toxic elements, PAH compounds), in general the health effects are not well enough understood for ambient air quality standards to have been written, but several are in the process now. If any of these pollutants are found to exceed standards, our results will clearly indicate which sources should be controlled to reduce the levels of these pollutants. In the specific case of urban refuse, already our findings have caused the Bureau of Mines to analyze the combustible fraction of refuse before the refuse is used on a wide scale to replace some of the fossil fuels in electric power plants.

ROUNDTABLE DISCUSSION

The most interesting questions dealt with the implications of our results, i.e., how are regulations for controlling air pollution going to change as a result of our findings? In reference to ozone production, the results suggest that control agencies will have to focus more attention on large point sources (versus motor vehicles) as the origin of ozone precursors. As yet, it is not known which precursors could be most efficiently controlled (e.g., nitrogen oxides or specific hydrocarbons), but if studies of the hydrocarbons are successful, this should be possible. Obviously, if terpenes from softwood forests turn out to be the key hydrocarbons, one would have to control something else.

Regarding the toxic elements, clearly, lead concentrations in the atmosphere should be reduced. Fortunately, this will happen automatically in most areas because of the phasing-in of autos equipped with catalytic convertors, which cannot burn leaded gasoline. Among the other elements, cadmium is the most likely threat to human health. Studies in Sweden and at Dartmouth suggest that the average urban resident takes in an amount of cadmium that places him close to the threshold of problems. There may be subtle, life-shortening effects of cadmium occurring now which go undetected. Levels of cadmium or other toxic elements in the atmosphere can be reduced by controlling the sources.

After further testing, this method of estimating strengths of various sources from the chemical compositions of their particles (chemical "fingerprints") can be used to determine the magnitudes of various types of contributing sources in cities more accurately than the presently used source-emission inventories.



6

ENVIRONMENTAL DESIGN

6. Environmental Design

RANN is currently assessing research needs in the area of environmental design. To further these efforts, five regional conferences were organized and conducted. These conferences addressed a variety of design issues and subjects. RANN program managers will evaluate the results of these conferences and determine whether a research program should be defined and initiated in the area of environmental design.

The first report describes the process whereby RANN determines the national needs which shall be addressed by research programs (Lagorio). A summary report of the findings of the five conferences provides the subject matter of the second paper which proposes one possible framework for organizing and evaluating the issues that could be researched and gives examples of types of research projects needed (Williams). Issues that may be productively addressed by the architectural profession are specified (Harkness). The applicability of the social and behavioral sciences to environmental design was focused upon at the Midwest conference (Kahn). At the Dallas conference, the role of urban design in local government was explored (Lu). Research needs in the area of environmental design in managing the impact of change were also considered (Ryan). The nerve center of the central city—its central business district or city center—was given special attention at one conference (Weiss).

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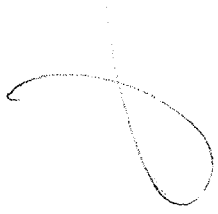
Panel Papers



Environmental Design and Man-Environment Relationships: An Assessment of Research Needs

Henry J. Lagorio
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Five regional conferences were organized and conducted by RANN grant recipients to identify the significance and consequences of the multidisciplinary environmental design process as it affects man-environment relationships. A sixth grant recipient will develop a summary report of the five conferences to synthesize and present results of the series. Grant recipients, architects, planners, social scientists, government representatives, entrepreneurial organizations, and economists associated with universities, research institutes, business firms, government agencies, and research foundations across the country convened to identify potential opportunities for research in environmental design and to define boundaries of the field.

Environmental design is seen as a multidisciplinary field which links research on environment and behavior with the design of the built environment as a basis for creating a productive relationship between society and its surrounding physical environment. The built environment is a principal focus for man's relationship to the natural environment. In dealing with basic physical and social aspects of man-environment relationships, the conference series emphasizes the need to improve the quality of the built environment through effective use of design and research efforts.

The national needs addressed by RANN research are determined by a process in which leaders of scientific and technical communities, academic institutions, industries and small business, state and local governments, and other government agencies participate. The criteria applied include consideration of the importance of the problem, the significance of research results, the leverage of science and technology on the problem, the readiness of an effort, the existence of suitable capabilities, the need for federal action, and the appropriateness of research support in meeting societal needs.

Six grants made in the area of environmental design serve as an example of a procedure by which RANN identifies and assesses research opportunities in an emerging field. Five regional conferences were organized and conducted in June 1976 by RANN grant recipients to identify the significance and consequences of the multidisciplinary environmental design process as it affects man-environment relationships. Specific recommendations were made in developing a potential research agenda. A sixth grant recipient developed a summary report of the five conferences in an initiative to synthesize and present results of the conference series in comprehensive form. Grant recipients and conference participants which included among other architects, physical planners, social scientists, economists, urban designers, legal counsels, government representatives, and developers associated with universities, research institutes, business firms, government agencies, and research foundations across the country convened to identify potential opportunities for research in environmental design and to assess research needs.

Environmental design is seen as an emerging multidisciplinary field which links research on environment and behavior with the design of the built environment as a basis for creating a productive relationship between society and its surrounding physical environment. Its institutional base relies on the capability and assurance that man-environment relationships and problems can be effectively encountered and addressed in the future as a means of improving the quality of life.

All conferences in the series had the same overall objective concerned with the identification of research opportunities in environmental design, but each conference contained a different theme to bring together the diverse ideas and experiences of this emerging field. The

themes, principal investigators, and location of the conferences, including the research center which assumed responsibility for synthesizing the results of the series, are as follows:

"Summary Report: Five Regional Environmental Design Conferences"
Donald L. Williams, Principal Investigator
Rice Center for Community Design and Research
Houston, Texas

"Environmental Continuity"
Richard Ludwig, Principal Investigator
College of Architecture and Urban Planning
University of Washington
Seattle, Washington

"City Centers in Transition"
Shirley F. Weiss, Principal Investigator
Center for Urban and Regional Studies
The University of North Carolina at Chapel Hill
Chapel Hill, North Carolina

"Urban Design Role in Local Government"
Weiming Lu, Principal Investigator
Planning and Urban Development
City of Dallas
Dallas, Texas

"Environmental Design Conference: The Practicing Architect and Societal Needs"
Sarah Harkness, Principal Investigator
The Architects Collaborative, Inc.
Cambridge, Massachusetts

"The Uses of Socio-Scientific Technology in Environmental Design"
Charles H. Kahn, Co-principal Investigator
School of Architecture and Urban Design
University of Kansas
Lawrence, Kansas
Robert B. Bechtel, Co-principal Investigator
Environmental Research and Development Foundation
Kansas City, Missouri

Environmental Design Research, 1976: A Summary Report of Five Regional Environmental Design Conferences Held in the United States During June 1976

Donald L. Williams*
Executive Director, Rice Center for Community Design and Research, Rice University.
C. P Sharpe
J. Linville

The purpose of this paper is to document the emerging state of the art of research into man-physical environment relationships, to identify shortcomings in such research programs, and to develop an agenda for further exploration. Five regional conferences involving environmental design practitioners, academicians and researchers, each conference to explore different aspects of environmental design research, are the bases of the report on which this paper is based. This summary paper proposes one possible framework for organizing and evaluating the broad range of issues that could be researched under the aegis of environmental design, and it then sorts the findings from the individual conferences within the proposed framework, resulting in examples of types of research projects needed in this field and recommendations for moving forward.

Five regional conferences were held during June 1976 to assess and identify research needs in environmental design and related fields. The conferences were funded by the National Science Foundation and RANN, the Division of Advanced Environmental Research and Technology, and the Division of Advanced Productivity Research and Technology, with the purpose of exploring the potential need for a research program in environmental design. The stated basic objectives included determining if these potential needs for an environmental design research program encompassed researchable issues and to identify the policy significance for those potentially successful research results in producing change.

Each conference developed proceedings and a final report. A sixth investigation was supported for the purpose of attending and observing the conferences and preparing a report which assembles, synthesizes, and interprets the key findings of the five conferences. The summary is not intended to represent a survey of the state of the art. It does not attempt to replace the individual reports which are rich in ideas and detail and worthy of attention individually, but rather to point out common findings of the various conferences, to indicate any variance among the conference findings, and, where obvious, to locate issues that may have been overlooked—any "gaps" in the proceedings—which could also become items for future study.

Throughout the individual conference reports there is an expressed need for the development of multidisciplinary research in environmental design fields as a means of anticipating and confronting environmental problems to mitigate some of them and to prevent, wherever possible, their drastic and unexpected occurrence in the future.

Both the recognition of research needs and the report indicate an awareness of the work in progress for a number of years by a small but very active group of people in the field of environmental design research.

In general, however, current environmental design research has been meager compared to the volume of environments designed and constructed in the past 20 years. Research has been fragmented and highly specialized, with small groups narrowly and vociferously defining the field, one suspects, for reasons of self-preservation in this under-supported area. For all the good efforts available, there is still a failure to maintain the kind of concentrated effort that seems required to obtain assistance in solving

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problems in the built environment and the social and economic relationships it affects.

The peer reviews of early drafts of the summary report point out some of the needs, frustrations, conflicts, and misunderstandings which always swirl around an emerging research effort. The peer reviews substantiate and challenge practically every point made in the summary report. While some of the reviews seem at least overprotective of a particular view of the field, others urge that environmental design research be allowed to more freely seek its topics, actors, methods, and edges over an extended period of time without the burdens of the past.

On the other hand, one must ask, how can the output from these five conferences not be taken seriously? Over 280 architects, social scientists, planners, landscape architects, engineers, and interior designers attended the five conferences. Among them were both researchers and practitioners of considerable stature as well as energetic and opinionated newcomers to the field. The conferences allowed for considerable input from the participants, and the conference reports generally reflect the diverse views of the participants. Thus, the summary and the five conference reports represent a fair cross section of *general* views and knowledge as of 1976. To the extent that details are missing or large gaps become obvious, one must take into account what conferences can and cannot do. More importantly, one should consider the possibility that this material reflects the level of information that is *generally* known among users and doers about environmental design research in 1976. There is a strong message when this entire effort is viewed in this manner.

RESULTS

Based upon information gained through attendance at the five regional environmental design conferences and careful review of the final reports of each group, the summary report finds a useful method for organizing and evaluating research in this field through the application of five categories: (1) What is the *physical environment* to be altered, and at what scale? (2) What is the *human response* upon which you wish to create a positive impact? (3) Who are the people or *affected groups* for which environmental design is being researched? (4) Who are the *actors necessary* to carry out the research and develop and implement improved design procedures? (5) What are the methodologies for designing productive research, and what are the mechanisms to insure timely implementation of the results?

Diversity was achieved in these conferences by spreading participation among different institutions, regions, and issues to be addressed. Although set up to gather data from the widest spectrum of participants, and although each conference debated a different issue with its own emphasis, several common themes (each requiring further research) were identified. The common issues and most often mentioned illustrative research topics were the following five areas.

Public Policy

The research problem most often articulated is lack of attention to design issues at relevant levels of governmental policymaking. Illustrative research topics are (1) study of the impact of public actions or lack of public actions on quality of design, (2) study of the effects of public policies on design, on social equity, health and safety, and the use of limited natural resources, and (3) development of legislation to insure design considerations in local government development decisions.

Human-Oriented Design Standards

The research problem also concerns criteria for the development of design and performance standards, and methods of implementing and enforcing such standards. Illustrative research topics are (1) development of methods to measure feelings of safety, security, neighborliness, mental and physical health, and the impact of design on each of these, (2) study of proper scale for implementation of standards, (3) pilot studies to determine the best ways to administer standards, and (4) development of criteria for performance standards, determination of proper scales at which standards could be applied, and methods to measure the performance of the built environment.

Application/Evaluation

The overall research goal is to find better ways of tying together research and practice, and evaluating the successes of design innovation. This priority issue lends itself to developing specialized methodologies under category five above. Illustrative methanisms are (1) post-occupancy evaluation of individual projects, (2) comparative case studies, and (3) environmental simulation.

Illustrative research topics are (1) development and enlargement of the methodological resources of the designer, (2) research into the effectiveness ranking of design review techniques, and (3) development of quantitative criteria for measuring success or improvement in design techniques.

Communication/Education

The major research goal is to increase the level of involvement, commitment, and use of design research by various groups. Tactics include the transfer, storage, and use of information; better citizen participation and awareness; and methods to compare and choose between design alternatives. Illustrative research-related activities include (1) establishment of research centers geographically located around the country to encourage better design research, to serve as repositories of information, and to bring together the prime actors in the field; (2) establishment of a national or regional clearinghouse(s) for environmental design research studies, with various publications developed to insure transfer of information; and (3) at the local scale, development of better mechanisms for citizen and community participation in design decisions.

State-of-the-Art Development

The overall goal of research is to develop a body of knowledge for use in environmental design. Research potentials are particularly broad within this need category, and the following illustrations touch only a few of the potentials: (1) identification of the various mixes of

population groups for which specific types of design must be developed, (2) comparisons of alternative approaches to specific design problems, (3) development of a comprehensive listing, analysis, and evaluation of types of research underway, completed, or projected, and (4) development of a dynamic framework for priority setting among specific research topics.

APPLICATION OF RESULTS

After listening to many voices over the past few months, the authors have made the following observations relative to moving environmental design research forward.

Environmental design research is a complex, applied research field, not new to many disciplines involved in individual research. It is a field that holds the promise of pinpointing some of the social and psychological impacts of the environment on man. And its potential as a category for rigorous scientific pursuit is practically unlimited. But, the field does require some openness and understanding from scientists in more established fields. It is relatively new and suffers from that affliction. It also is multidisciplinary and must break several communication barriers. The problem statements needing research often cut across several traditional disciplines, and are not easily broken into discrete parts that lend themselves to previous divisions of scientific analysis. While the established hard sciences tackle complex issues by spending extraordinary time on their component parts, environmental design issues deal with comprehensive interrelationships that may not be subject to solution by division into discrete parts.

The area is limited by a lack of funds and resources to support a stable and rigorous researh program. Hence, a major theme throughout the conference of 1976 was the need for federal government support to enable the architects, the planners, the social scientists, the urban designers, and others interested in the field to pursue research. But problems go deeper than money, though additional funding of environmental design research is certainly a necessity. Many of the interested participants are practitioners in the art of building human environments. They are the doers who are natural users of research, but they are not normally trained in the scientific methods of the researcher (a generalization that does not apply universally). After the conferences, and based upon several years experience managing research in the field, the authors believe there is a potential manpower problem. Gerald McCue discusses this problem in his report on the future of the architectural profession, *Creating the Human Environment,* University of Illinois Press, 1970.

In the authors' opinion, there is no indication that the last six years have seen an increase in research manpower available to the environmental design research field. This suggests some early efforts at creating additional research manpower in both professional, education, and professional practice should pay off in long-term dividends.

During this project it has become obvious that this developing field has its factions, each vying for the opportunity to sell its point of view as the sole foundation on which to build the environmental design research field. While this is not an unusual occurrence, it could be disruptive to a new or emerging field. For this reason the authors recommend openness on the part of funding sources. This openness should include topics to be researched and methods to be used as well as the researchers to be supported. In this developing field, newcomers and new ideas are as essential as are quality of research and usefulness.

To proceed effectively and efficiently, funding sources, researchers, and users need some basic information:

- *State of the Art:* Even though there are several claims that state of the art surveys are available, it appears that current surveys are not comprehensive and are very limited in scope. We recommend that a broad survey and evaluation of the state of the art of environmental research be completed as soon as possible. This project should include not only research completed and in progress, but also the manpower availability and potential current funding support.
- *Information Dissemination:* A considerable payoff seems possible through the collection, reformatting, and dissemination of completed environmental design-related research to potential users. This effort can begin as a separate effort but eventually should be tied to the above state of the art project.

Two additional steps can be taken immediately:

- *Example Projects:* Five to 10 research projects should be funded as soon as possible to demonstrate the broad range of topics in the field; their vulnerability to research application; and the potential for immediate payoff to society. The wealth of research topics contained in the five conference recommendations plus the summary offers the shopping list for choosing the topics. The problem will be in the choosing among many worthy subjects. Careful selection should produce a set of projects that, when put together, can produce a significant impact on the field.
- *Program Objectives:* This field could benefit greatly from the development of program objectives, both long and short term. The short-term program should aim at objectives that will achieve results within 10 years; the long term within 25 years.

In summary, the future of environmental design research rests with two principal sets of actors—the financial supporters of research and the potential doers of that research.

The funding institutions must be encouraged to accept research designs that are "softer" than those they normally see from physicists, biologists, or chemists, and which pursue no less rigorous but more general courses of action. And they must be encouraged to invest greater resources and look toward both short-term and long-term payoffs.

The participants in environmental design, on the other hand, must accept responsibility for more clearly and explicitly defining their goals, developing better research tools for exploring unconventional topics, and laying effective ground rules for further research.

Finally, since the nature of the research is undoubtedly multidisciplinary, better methods of creating communication among previously unrelated professions and disciplines must be achieved. Those groups who must learn to communicate needs and requirements to one another include not only environmental design scientists and practitioners, but also the public and private decision-makers, all of whom are struggling with improving the environment in which man lives.

The Practicing Architect and Societal Needs

Sarah P. Harkness*
Director, Architects Collaborative, Inc.
James N. Groom

Organized by The Architects Collaborative, Inc., the purpose of the conference on "The Practicing Architect and Societal Needs" was to uncover, explore, and recommend researchable issues that may be productively addressed by the architectural profession.

The classic pattern of architecture, which reached a high point in the post-World War II period of uncontrolled growth, is now changing to meet current realities. Limited growth is accompanied by a new appreciation of the nation's heritage, exploration of alternative sources of energy, and changes in lifestyles and institutions.

How can architectural capabilities be used to meet the new situations? How should architects change?

Seventy participants, 50 percent architects and 50 percent non-architects, agreed that multidisciplinary cooperation is essential to answer today's problems in environmental design. Proposals were made for research to be done by and for the architectural profession.

The purpose of the conference on "The Practicing Architect and Societal Needs" was to uncover, explore, and recommend researchable issues that may be productively addressed by the architectural profession. It was a chance to look ahead at a time when the practice of architecture is in a state of change. The classic pattern, which reached a high point in the post World War II period of uncontrolled growth, is now changing to adapt to a situation of limited growth. With limited growth comes a new appreciation of the nation's heritage, exploration of alternative resources, and understanding of changes in lifestyle and institutions.

Even during the building boom, a change was already taking place in the nature of the client. Instead of an owner/user whose responsibility was to provide the program and all necessary or pertinent background information and whose satisfaction would be in the enjoyment of the final product, the client is now more often than not a board of trustees, a developer, a building committee, or an agency—a multiple client like an "uncle once-removed" from the actual project.

To get back to present-day changes, it appears that limited growth and limited energy are simultaneous, if not synonymous. Since buildings in this country use 33 percent of the total energy consumed, the relation between new buildings and energy availability is obvious. There are not so many opportunities to build nice, new monumental buildings surrounded with grass as there used to be. To find this kind of job, some architects are now in the "off-shore drilling" stage. In a talk given at our conference, Frank Keefe, director of the Massachusetts Office of State Planning, referred to architecture in this state as an "export industry."

Practicing architects have responded to external changes in several ways. There are two discernible trends, which seem very different from each other. One is the effort to beat the economy by building with greater speed and efficiency through methods such as Design-Build, Systems Building, Fast Track, Construction Management, and the like.

The other trend involves the user community in the entire design process. Speed is not the ultimate objective; in fact, the project may be in the planning stage for years, preceded by programming and feasibility studies.

The architectural profession is responding to change, and is in itself changing, and the changes are taking many directions. Is there any common denominator among the

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changes? It seems that there is, and therein lies the need for research.

First, with the removal of the owner/client from the immediacy of caring, using, and ultimate satisfaction, we can't expect to be told what's needed in a particular type of building for a certain type of client, but must find out for ourselves.

Second, limited growth, necessitating re-use and renewal of existing buildings, leads to a sudden appreciation of this country's history; and limited energy from conventional sources leads us to explore the use of alternate sources of energy, such as solar, and to develop a new aesthetic of resource-conscious design.

Third, any speedy system of delivery must be based on research that has preceded the writing of a clear, thorough program. Fourth, community involvement in design is a form of research in itself; research throughout the project to assure that whatever is built will be the right thing to build, in the right place, to answer the needs of the particular people.

Therefore, the need for practicing architects to become more involved in research is evident. However, one problem remains—how to get paid for it. *Who* pays for it—those who will profit, or an outside agency—and when and how? Generally, the usual fee structure for architectural services does not include payment for research, and architects in general do not make the kind of profits that could be put into research and development. With all of this, it was an especially propitious time for a conference on "The Practicing Architect and Societal Needs."

The conference included 70 architects and related professionals, using a workshop format to respond to talks by major speakers on land use, energy, social concerns, and changing institutions. If there is one thing that came out loud and clear at the conference, it was the enthusiasm of the participants. If the medium is the message, one message is that there must be a great need for people from different professions, whose work has to do with different aspects of the same general subjects, to meet and talk together, and plan to work together.

The conference members expressed the need and desire for the architectural profession to assume a broader perspective that could better answer societal needs through interdisciplinary teamwork. The need for research by and for the architectural profession was part of this thinking. There are two basic reasons for the recognition of the need to change: economic necessity (need for finding new work), and realization that shortages of energy and natural resources, unanswered societal needs, and the ecological point of view can be dealt with in no other way than through interdisciplinary teamwork.

The subjects addressed by the conference could be divided in two groups: nuts and bolts issues and social issues. The greatest number of tangible recommendations for research projects came out of the workshop on nuts and bolts issues—land use, transportation, life style, and energy awareness and design. Less definitive recommendations came out of the workshops on social concerns affecting the design process, and changes in education and social services, but in these more socially oriented groups, there was strong emphasis on the need for interdisciplinary teamwork and better methods of sharing information. A third area of discussion was about the architectural profession: its traditional, present, and possible future roles.

Many of the same expressions of need (leading to research) came up repeatedly in the workshops, regardless of the subject of the workshop. These were:

- With limited natural resources, the responsibility to make each design decision count.
- The need for interdisciplinary team action.
- The need for a clearinghouse for information and better means of communication.
- Revision of professional education to include training in research techniques.
- Post-occupancy evaluation, study of case histories, and development of prototype designs.
- Revision of the reward structure for architects and environmental designers.

Suggestions for research were sometimes extremely broad, sometimes quite specific. Some broad ones were:

- What are the forces that currently divide the architectural profession from society?
- Identify real world issues and make a study for planned change.
- What are the workable alternatives to crisis?
- Find alternative ways of making people comfortable.

Some specific recommendations for research were:

- Delineation of a segmented market for small transportation systems. Is there a luxury market at premium prices?
- Analyze thoroughly the true cost of oil and nuclear power to the taxpayer.
- Consider the effect of alternate energy strategies on master planning concepts and procedures.
- Investigate the consequences and uses of new fuels (i.e., wood).
- Which existing buildings, or building types, have proved to be the most enduring through changing uses, and the least inhibitive of change?

Another conference could be built around the theme of defining environmental design research. However, to arrive at a definition in an abstract or academic way might be less productive than allowing the definition to evolve by addressing practical issues. With the conference behind us and influencing what we say, the following are some tentative answers.

We should differentiate between "environmental research" and "environmental design research." The first can include studies of air and water pollution, climate, soil, geology, natural resources, human ecology, and any number of other things that have to do with the (usually) natural environment. But when we speak of environmental design research, human intervention is involved. This research is used to influence design solutions (studying traffic to determine siting of a building, for example); or to anticipate design (feasibility studies, for ex-

ample, or the setting of guidelines for future projects). We are speaking of the impact of design by and on people through the intervention of design professionals.

Architects and architectural schools are broadening the scope of what they do or teach, partly because of the number of elements that must be considered in any project, and partly because there is simply not enough traditional architectural work to go around. Double degrees, such as in architecture and engineering, architecture and law, architecture and social sciences, are becoming frequent. This is all to the good. However, for the public to know what to expect of a so-called "architect," there should be more differentiation in degrees and titles. When is an architect not an architect? Perhaps an answer would be when he or she has left the design of buildings or environment behind, either as an activity or as an ultimate objective. There was no doubt expressed at the conference that research was a viable activity for architects. However, some of the researchable issues that were defined and listed would seem to represent needs of the architect for information that could be compiled or researched by non-architects, while other researchable issues listed would be more appropriately addressed by the architects (or environmental designers) themselves. Interdisciplinary coordination is essential, but responsibilities of the team members should be defined.

The significance of environmental design research must be measured by its effects on the environment. "Design" is often thought of as a visual thing, but it must be remembered that it also includes efficiency, workability, comfort and pleasure, and all the humanistic values. Environmental design research, then, as done by architects, should incorporate all the traditional skills of architects in design and synthesis, but is likely to be more of a team project with other disciplines and is likely to have a general or hypothetical application, as opposed to the intuitive and pragmatic decision-making process that must be applied to traditional architectural projects.

The Application of the Social and Behavioral Sciences to Environmental Design

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The Midwest conference focused on the issue of the applicability of the social and behavioral sciences to environmental design. Two architects in private practice and four social scientists active in the field made formal presentations to an invited group of architects, representatives from the building sector of state government, and from regional offices of similar areas of the federal government. Using a case study approach, each of the speakers related his or her experiences in the colaborative effort between architects and social scientists. Question and answer periods followed each session. At the end of the formal presentations, the participants formed small study groups to make suggestions concerning a research agenda aimed at increasing the dependability and activity level of such collaborations. The participants were asked to structure their responses into three areas: basic research needs, translation of basic research into applied research, and communications infrastructures for information dissemination.

The Lawrence/Kansas City conference was the fourth of five regional conferences held in various parts of the country. Each conference was free to choose a theme that represented individual strengths and professional interests of the convenors, as long as those interests matched areas of perceived interest of the National Science Foundation (NSF). The one constant theme which tied all five conferences together was the desire of the NSF to assist in the articulation of a research agenda in the broad area of the environment and environmental design.

It was the intention of this conference to focus on the effective application of the social and behavioral sciences to environmental design. Before the contemporary trend toward specialization, consideration of social science issues was an accepted function of sensitive, talented architects. We are now seeking broader, more formalized methods for such considerations. To structure this process, three basic questions were addressed at the conference:

(1) Is there a necessity to develop more basic information? In other words, does the genesis of the problem of applicability lie in the area of insufficient basic knowledge, the inference of which is that emphasis must be placed on basic research and an acceptance of the limitations of the present "state-of-the-art" knowledge in the area?

(2) Is there a necessity to develop processes for applying the existing basic knowledge, assumed to be sufficient in the particular area, to environmental problems? That is, given the state of the art of knowledge in an area, is the problem one of developing dependable mechanisms for taking that existing basic research knowledge and transferring it into applied form? It seems to be automatically assumed not only that basic knowledge itself is directly transferable into applied situations but that basic knowledge from one discipline is equally transferable into an applied capability in other disciplines, whether related or not. This is not necessarily the case in either instance.

(3) Is an informational infrastructure needed for the dissemination of both basic and applied knowledge to those in practice who will use

such information in their daily professional lives and in the solution of real problems in the real world?

Since the mix of speakers included consumers (architects in private practice), consultants (behavioral scientists), and individuals with reasonable expertise in both roles, it was possible to show the successes and problems of collaboration with social scientists and to identify areas where research, both basic and applied, is needed to assist the design professions.

One investigator during the planning period felt that the major purpose of such a meeting was to develop a system for the dissemination of information concerning the utilization of socioscientific technology by architects, which assumes that a usable body of definitive information exists. This presupposes both the existence of sufficient basic and applied information to comprise an acceptable level of well-developed and substantial knowledge, as well as functional linkage mechanisms between the social sciences and the environmental design professions, and assumes needed activity in only the third area.

The other principal investigator felt that this assumption is only partly valid and that the applicability of these social science skills to environmental design requires a radically different perspective in seeking solutions and in establishing an agenda for the resolution of such problems through research. The essence of this second position is that the precise character of the issues to be attacked in setting research priorities, as well as defining where the real problems lie in the transferability of the knowledge and processes of one set of disciplines to another, have yet to be clearly articulated.

Before comments are made on the conference and its results, it might be beneficial to summarize my opinion of the salient points made by each of the invited speakers.

Neal Deasy emphasized the positive nature of his experiences with the social sciences over the past decade of his architectural practice. He emphasized the observation study as the most important component of the social science impact on his design process, an activity which allowed him to identify objectives, problems, and eventually, disappointments. However, his proposal for institutionalizing this activity is somewhat suspect. Deasy's suggestion of a handbook of pre-translated data for such information runs the risk of further diluting the ability of the architect to observe for her or himself. Such a danger, which has an analogy in the use of the Parker handbook series in the application of structures to architecture, suggests that perhaps the best contribution the social scientist can make at this time is to retrain the architect in observation techniques, a traditional ability of better architects, rather than expend the energy required to develop a codification of pre-digested observations.

In contrast to Neal Deasy, Lou Sauer was extremely skeptical of the social scientist's ability to bring the power of his or her discipline to bear on design, given the present state of the art. Sauer pointed out the obvious difficulty of dealing with an anonymous client, as is usually the case in the area of the built environment. His experience has been that the social scientist is not at that stage in the application of his or her body of knowledge where he or she is able to adequately cope with the uncertainty resulting from that anonymity. Consequently, he discovered that more often than not his collaboration with the social scientist would result in the latter pointing out to him the obvious, rather than responding to the questions he raised. What was even more devastating to Sauer was the realization that the social scientist operates with the same degree of subjective reasoning as the architect and that the ostensibly rigorous scientific method of the social researcher results in little hard-edge data on which to base design decisions. Finally, Sauer observed that in a number of his experiences, the economist would give the designer more definitive data about client preferences and predictive behavior than could social or psychological scientist.

Next, three social scientists in the area of environmental design presented their views. Bob Sommer percieved that perhaps the main function of the social scientist might be to sensitize the architect to the concerns of the user. Sommer placed a strong emphasis on the user ethic in design and made a plea for institutional arrangements to support the behavioral aspects of design research, an issue consistently raised by all of the social scientists at the meeting. He also discussed the advantage of having students in an institutional setting for observational studies. Moreover, one of the main issues he emphasized was the importance of post-construction evaluation as an essential element in the feedback system for design. It is interesting to note that post-construction evaluation is, to a great extent, an observational mechanism.

Ed Ostrander attempted to demystify the social sciences. His plea was for the acceptance of scientific inquiry without overwhelming numerical preoccupation. He was the only social scientist to make a clear statement of the potential irrelevance to design of much of the so-called man/environment research. He related this to the assumptive world in which we all live and again emphasized the importance of observation as a technique for defining the parameters of design. Most importantly, Ostrander said the social scientist could transfer the observational expertise of the discipline to the architect and others and accepted the legitimacy of the architect in such activities.

Lee Pastalan made two important points. The first was to recognize the traditional observational skill of the architect and encourage its nurturing and revival. He also suggested the immediate applicability of the social sciences to design more through their relevance to restricted, homogeneous subsets of the population (e.g., the elderly) than to the general population.

Janet Reizenstein commenced the final formal presentation by defining the architect as incapable of empathy with the user client. In what appeared to be a self-serving definition of role playing, she reestablished the social science mystique so effectively down-played by Ostrander the day before. Although not intentionally, she provided a perfect example of Sauer's observation of the development of obvious, useless information: "Architects reported (in her questionnaire) a tendency to use research

findings related to small-scale environments, whereas planners reported a tendency to use findings related to large-scale environments." However, the bulk of her presentation was preoccupied with her perception of the necessity of convincing architects, and other potential consumers, of the benefits of collaboration with social scientists and with a detailed study of potential funding sources and strategies for operationalizing them.

After the formal presentations were completed, the participants at the conference were divided into small task groups to make recommendations concerning potentially attractive areas for environmental research.

At the beginning of the conference, the possible identifiable research issues were organized into three related groups: issues requiring the development of new knowledge through more basic research; issues requiring the translation of basic research into applied techniques; and issues involving the need for information infrastructures to disseminate already developed applicable knowledge. The stated recommendations resulting from the conference break down as follows:

Basic Research Items	4
Applied Research Items	17
Communications Items	11

In the perception of the majority of the professionals present, the required basic knowledge for the application of the social sciences to design and the professionals capable of delivering that knowledge both exist. This would intimate that the professional architects accept the position of the majority of social scientists on these issues. Moreover, if the most often-stated issues are accepted as indicative of where the major problems inhibiting wide-scale application of this body of knowledge lie, two issues would be predominant:

(1) Language: The reason social science information cannot be applied to design is because of the closed language system of the social scientist (i.e., the problem of translation from one discipline, the basic researcher, to another, the practitioner).

(2) Communications infrastructure: The dissemination of such knowledge to the potential user.

Other valid issues not raised or not discussed fully include:

- What is the true extent of defensible basic research information about human behavior, either individual or group?
- Can the existing basic research information on human behavior developed by social scientists over a relatively long period of time to satisfy their own agendas be translated into the basic research on which to develop design-relevant capabilities?
- As a corollary, does a completely new fund of basic research need to be developed specifically following the agenda of the architect and environmental social scientist before reasonably dependable applied procedures can evolve?
- How does the researcher, social scientist or architect, take into account the largely anonymous character of the client in the actual process of making decisions for the built environment?
- What is the effect of desirable physical facility flexibility on the dependability of social science research as a design input?
- As a corollary to the previous question, are different basic research principles and/or applied research techniques required for both general spaces (offices, classrooms, etc.) and unique spaces (auditoriums, concert halls, theaters)?
- As a second corollary, should we expect the application of social science research to be more reasonable for certain well-defined, more homogeneous groups (e.g., the aged, paraplegics, etc.) than it is for the more heterogeneous groups of the general society? The acceptance of such a thesis inevitably would lead to an attempt to identify those groups for whom such techniques are most valid, with a consequent diminution of the pressure at this time to seek hard edges for areas for which such results are not now available.

These questions propose a much more basic problem than was addressed at the conference. The preconceptions each group of participants brought to the conference structured the way they responded to the question of identifying the origin of a commonly felt deficiency in evnironmental design. The architects came to the conference dissatisfied with the information on which they base physical design solutions for environmental problems.

During the past several decades, for a variety of reasons, architects have developed deep misgivings about the defensibility of their decision processes. Mainly as a result of pressures from the academic component of their professions, they have sought some relief for these feelings of inadequacy through involvement with a number of disciplines with more rigorously defined procedures. Certainly the claims of the social scientists during the past decade have conditioned architects to expect information and techniques from them to replace the traditional base of information and relatively subjective decision models upon which the architect has depended.

The social scientist has welcomed the opportunity to move from pure theory to techniques applied in the real environment. In this way the environmental psychologist sees the potential collaboration with the architect as affording the equivalent of a clinical outlet of his or her more traditional colleagues. It is perhaps because of this strong symbiotic need of each group for the other that neither has been able to address more fundamental questions or accept the reality of undesired constraints.

Perhaps the most significant contribution the social scientist can make to the environmental designer, while we initiate basic research, is to retrain the designer to sensitively and intelligently perform a task in which he or she has traditionally been very effective. Sensitive, creative designers have always had the ability to observe the use of built environments, to abstract from those

observations pertinent information, and to synthesize the results into effective environments. In this fashion, good architects have always been conducting post-construction evaluations for the built environment. The change from that process of design, as Janet Reizenstein correctly points out, to one centered mainly around the study of typical architectural magazine presentations has been a major blow to the process of seeking a uniformly higher quality in the built environment. Just as the elevation of design process to an end in itself rather than as a means to an end has partially debilitated a generation of designers, so the establishment of style by Kodachrome photographic journalism has divorced the architect from the reality of people in the environment.

In the early 1920s, architecture voluntarily abdicated its role in the development of the character of the residential portion of the American environment and opted for the corporate client. Since that time, the profession has consistently bemoaned its involvement with barely five percent of the built environment. In addition, should architecture now abdicate to the social scientist its traditional function of observation, analysis, and synthesis, its involvement in the built environment will continue to decrease and the vestigial remnants of the profession will have changed their character radically and irrevocably.

Urban Design Role in Local Government

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The Dallas Conference stressed the viability and increasing importance of urban environmental design in solving the problems of our cities. Local governments need research to help them improve the design and management of their urban environments. As the primary users of research, they should also play a key role in defining research needs and carrying out the research itself. Much remains to be done before cities can fully benefit from improved urban design. There is insufficient understanding at all levels of government of the role that urban design can play. The conference outlined three categories of urban design policy: performance standards, environmental impact statements, and four types of mechanisms for implementing urban design in local governments. Also noted were seven major deficiencies in urban design research today, three tentative models for describing the urban development field, and three alternate approaches to urban design research. Research needs were suggested in the area of design administration, design legislation, design issues, and communication and education.

To be useful, urban environmental design research must take a holistic approach continuing in one place over long periods of time; be integrated into project organization, implementation, and evaluation; and be done by those who are part of the project being studied. There is also a great need to improve dissemination of research findings.

The Dallas Conference on the Role of Urban Design in Local Government made it clear that urban design practice is maturing rapidly and becoming broader and more effective. To continue this development, research is badly needed in a number of areas. Such research must focus on the needs of local government as the key agent of urban design implementation; local government too must take a leading role in carrying out urban design research. The importance of the public sector in achieving high quality urban design may be understood by considering that often half of the land in a city is publicly owned, and private development is subject to public influence and control.

Though the importance and effectiveness of urban design is certainly increasing, much remains to be done before cities avail themselves fully of the potential benefits of improved urban design. At all levels of government there is insufficient understanding of the role that urban design can play. Urban design efforts do not receive adequate fiscal support from federal, state, and local government agencies. At the local level, while more city governments are paying attention to urban design, the mechanisms for its functioning remain poorly defined and supported.

Fostering an urban design movement in America in the years ahead will depend on meaningful citizen involvement in the urban design process and on adequate urban design implementation mechanisms in local government. As long as there is a context in which urban design programs can take root, there will always be opportunity to improve design methodology.

With regard to implementation, three major elements are of critical importance. First is the public's attitude toward and participation in the design process. Designers and "consumers" of urban design must be equal partners here, for each has much to teach the other in the process of achieving a better environment in which to live and work. At least two levels of public participation are required in the implementation of urban design, broad-based general goal-setting efforts for a city as a whole, and participation by specific interest groups affected by particular design issues or projects. In addition, the public's understanding of design issues can be strengthened by exposing it to examples of good urban design, by meaningful public debate, and by improved post-construction evaluation of projects.

A second critical element is the legal framework within which urban design must be implemented. Certain basic

legal powers are essential to the successful implementation of design, and certain techniques can be useful in fostering that success. Relevant legislation can be classed in three categories of "as-of-right" administration, elective design review, and mandatory design review. In addition to these three types of legislative techniques, performance standards and federally mandated environmental impact statements are also among the basic repertoire of tools of this type. As-of-right ordinances are most used in this country and are valued for their brevity and uniform applicability. Their inflexibility and permissiveness have led to increased use of the incentives available under elective design reviews varied forms—incentive zoning, development rights transfer, special districting, restrictive covenants, planned unit development, and growth management schemes. Stronger yet are the directives of mandatory design review, usually used in districts established to protect critical resources.

Development control ordinances written in the form of performance standards rather than specification standards offer important advantages over traditional methods. While more complex, they can be changed more easily in accord with changing needs. They help predict more accurately the effects of development and are more flexible. It may be possible to reduce the high administrative costs usually associated with performance standards by developing prototype situations, use of performance-based standards, use of paraprofessionals, and more accurate measurement of the indirect costs associated with other types of development.

Environmental impact statements required by federal law for key projects have potential to help achieve a better designed urban environment. The fact that these statements have not been used with regard to the built environment except in a few cases, and numerous administrative problems, render them less effective as a tool than they might be.

A third crucial element is the structure, or mechanism, by which urban design is implemented in local government. The conference outlined four models of such mechanisms: the ad hoc problem-focused concept, the multiagency dispersal concept, the key or lead agency concept, and the ombudsman concept. Common characteristics of effective mechanisms of all types are: (1) the design office has direct lines of communication with key decision-makers; (2) urban design office has mandatory referrals and design review powers; (3) continuing communication with the varied business and public interest groups in the city; (4) adequate budget, competent staff, and effective management organization; and (5) multidisciplinary staff in house, complemented by selective use of consultants. The four models need to be studied carefully to determine (1) to what degree each corresponds to reality; (2) how actual practice under each model varies from city to city; and (3) how each model may be used best to provide leadership or impetus for improved design and management of the urban environment.

Certain characteristics, conferees agreed, distinguish useful urban design research from that in other fields. First, urban design is an explicitly normative field, concerned with creating new possibilities rather than dealing primarily with what is already in existence. Too, it deals with human beings and with scarce, irreplaceable resources. Thus, useful research in the field must (1) be carried out as an integral part of a project's organization, implementation, and evaluation; (2) continue in one place over long periods of time, to allow for successive modifications based on results of research; (3) be designed so that failures can be rescued when they occur; (4) be carried out by those who are part of the project being studied; and (5) attempt to incorporate methods of disseminating the results to professionals most likely to use them.

Several major blocks exist to effective utilization of urban design research. First, much of the research done is irrelevant to the problems and priorities of urban designers practicing in the real world. Second, useful research findings are not readily available to practicing urban designers. Third, useful research findings are not being employed effectively, if at all, by local governments. Fourth, though local governments often have a wealth of researchable information, this information is not utilized. Fifth, research need not be carried out only by universities and research insitutions; local governments under certain conditions can also initiate, sponsor, and/or conduct innovative research. Sixth, case studies are needed to document success and failure in urban design. Seventh, many individual research projects are carried out with an inadequate frame of reference, resulting in many results which are not cumulative or comparable and so do not add up to coherent wholes useful to designers in their work.

To help in developing the needed frame of reference to describe the urban design process and field, three tentative models were offered: "People Make Environment," "Sensory Quality of the Physical Environment," and "Product-Process-Discipline." These three models offer different ways of looking at the subject matter for urban design research.

Three alternative approaches to urban design research were outlined: (1) contextual, (2) "trickle-up," and (3) post-construction. All serve important needs, and the three are not mutually exclusive. Contextual research is that which is an ongoing case study conceived and carried out as an integral part of the design-decision-implementation-management of a project. "Trickle-up" research begins with a very small problem or focus and works out from that toward larger issues and contexts. Post-construction research is evaluative in nature and focuses on the successes or failures of a given project, and the causes of these results.

Specific research topics were suggested under the headings of design administration, design legislation, design issues, and communication and education, in order of importance. Higher priority should be given to research on design process than on design product.

Design administration research needs focus on evaluation of various urban design mechanisms in local government, management of the design process, impact of public investment in infrastructure, use of paraprofessionals, effectiveness of urban design assistance programs, and the development of innovative settings.

In design legislation, suggested research topics included the side effects of ordinary codes and regulations; costs and benefits of development control measures such as incentive zoning; use of performance standards in design legislation; costs and effectiveness of various design review techniques; development and effectiveness of various design criteria; and the EIS process or alternatives to it.

With regard to design issues, problems cited included measuring direct and hidden costs of developments; environmental management techniques; rehabilitation of older suburban areas; influence of energy use on design; appropriate environmental modification scale; users experience of various environment; impact of density on environmental users; mixing of residential and commercial uses, and of socioeconomic groups, in a given environment; and study of recurring patterns of settlement.

Areas suggested for study in connection with communication and education included ways of using the environment for learning; simple, low-cost simulation and prediction techniques; motivations of decision-makers; use of volunteers; use of local craftsmen; ways to convert environmental "consumers" into "producers"; ways to use university resources to enhance the community's design programs; and mid-career training for design professionals.

The conference also drafted a list of additional legislative and governmental needs on the federal, state, and local government levels. These recommendations stressed that the Tenth Amendment, which reserves to the states powers not explicitly granted to the federal government by the Constitution, should be preserved. The federal government should set very basic urban design guidelines and policies, but leave development of specific standards and enforcement to the state and local governments.

Within federal government, needs include better coordination among agencies, greater leadership on the part of professional organizations and federal employees, and categorical grant programs involving ubran design and historic preservation.

State government needs include setting examples in state-funded projects; appropriations and incentives for local urban design projects; state override on crucial local government decisions; enabling legislation for local design review; support for state arts councils; and stronger role for state-employed design professionals.

On the local government level, cited needs were for required urban design plans and guidelines in local development plans: careful balance of design goals and concern for due process in design review; effective administrative mechanisms for urban design; urban design considerations integrated into city budgets and capital improvements programs; and effective citizen involvement in the design process.

Research Needs in Environmental Design and Continuity

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The questions, "What are the research needs in the field of environmental design?" and "What is the role of environmental design in managing the impacts of change?" were asked. A multidisciplinary team of both researchers and users of research in environmental design formulated three categories of responses: (1) Environmental design needs to improve its analytical tool kit and its methods of translating theory and information into usable form; (2) a greater understanding of people's need for continuity and ways to achieve it through environmental design should be developed; and (3) usefulness, creativity, and organization should be emphasized as evaluation criteria for environmental design research. Conference findings will be used to provide focus and support in environmental design research.

The theme addressed by the 67 practitioners, educators, public officials, and researchers in environmental design at the RANN-sponsored Seattle conference was "Research Needs in Environmental Design and Continuity." It is a theme which suggests a major thrust of environmental design research activities in the future if present trends and issues facing the field are read correctly. The increasing public pressures for urban growth limits and new management techniques, preservation legislation, neighborhood conservation programs and the like seem to indicate that people want some degree of continuity in their environments as change takes place. And they want environmental designers to be more responsive to this concern; they want us to be able to deliver the goods in this crucial area of managing the impacts of change.

Environmental continuity proved to be a good theme for several reasons: (1) It provides a "neutral turf" to bring together a number of design disciplines including those who conduct research as well as those who normally use its products; (2) it hits on a major role of the designer, that of recommending ways of managing environmental change; and (3) it has meaning at all scales, from neighborhoods to regions.

Seattle's recommendations fall into three major categories. All of them should be considered in the context of two overriding concerns of the participants: (1) The need to develop further the underlying theory base of environmental design and (2) the need to improve our methods for approaching the dynamic problems associated with environmental change.

One set of conference findings pertains to research needs for environmental design in general. Priorities here include the need for building up the analytical "tool kit" of the designer and for translating and communicating research information into forms that are useful to professionals. We need better methods for predicting and forecasting the consequences of alternative design actions as well as improved tools for analyzing the dynamics of the present; tools for gathering information, for problem identification, and for determining user values. Furthermore, we need to develop our techniques for evaluating and monitoring the built environment. There was a call for substantive research in the subjects of person-environment relationships, environmental change, and the governmental or public policy context of

urban design. We need to be much better able to determine an environment's susceptibility to change and to understand people's perception and reaction to it. We also need to make sure significant advances are made in developing methods to resolve conflicts in environmental issues and to involve the public in the design process. In short, research subjects of who, what, and how.

Another set of research needs pertains more specifically and directly to the conference theme. The emphasis here was on the need to develop a better understanding of people's reactions to environmental change and their needs for continuity as well as ways to achieve it through environmental design. Participants suggested that the entire theoretical basis of environmental design be advanced by focusing on the concepts of change and continuity. They also recommend that some of the structural roles be delineated that would describe the attributes, limits, conditions of existence, and effects of continuity. Along similar lines, they felt it would be beneficial to develop solution conceptualizations or alternative program approaches for achieving environmental continuity in various situations. And there was unanimous agreement that there should be a balance between quantitative and qualitative research in the environmental design field.

The final category of findings are criteria for setting priorities and evaluating research proposals. For example, recommendations emphasized that high risk or new ventures with "unknown" researchers be supported. Also, that synthesizing be recognized as an extremely valuable activity in environmental design, as valuable as the breaking of new ground.

Those, in a three-minute nutshell, are the overall recommendations from the Seattle conference.

Now I want to describe one of several research ventures derived from the conference recommendations. These ventures integrated a number of research needs as you can tell from their general titles, such as: (1) Environmental Change Thresholds, (2) Case Studies in Environmental Design, (3) Conflict Resolution, (4) Environmental Maintenance and Reinvestment, and (5) Images of Environmental Change and Stability.

All of these ventures are aimed at improving the state of the art of urban design. For example, "Environmental Change Thresholds" is a venture that could build upon current abilities. Environmental designers have rather recently been using concepts such as "thresholds of damage" and "carrying capacities" with some success, particularly in cases involving the natural environment. Why not encourage the development of similar techniques tailored specifically to what is called the built environment? Why not seek to identify the change thresholds of communities in both physical and socio-behavioral terms? Thresholds, in this broader sense, would be a term to describe the degree to which a community could change before it passed the point of irreversible damage as perceived by its residents. The thresholds would be a way of determining how much change could be accommodated while still retaining those attributes of the physical and social environment valued by current users.

Some research projects which could fall under the threshold venture include:

- Developing better means for measuring the susceptibility of an environment to change (social change, physical change, economic change, etc.)
- Improving the designer's methods for measuring and defining community or user values and perceptions of environment. Also improving our methods for identifying needs, objectives, and priorities related to the environment.
- Development of environmental monitoring systems that are both practical and sufficiently sensitive to guide urban design policymaking and program formulation.

That, very briefly, is one of several ventures that comes out of the Seattle conference recommendations. I hope it, together with the quick overview of the findings, provides you with some idea of what the 67 participants, meeting in Seattle, felt needs to be done, how it might be done, and why.

Conference on City Centers in Transition—Redesigning the Urban Environment for New Patterns of Living

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This conference focused on the nerve center of the central city—the central business district or city center. Major objectives were to provide public agencies, practitioners, and the scholarly community with an improved basis for (1) identifying the critical processes and decisions that are transforming city centers and (2) isolating key research needs and identifying their significance for public policy. The conference affirmed the belief that city centers serve important functions and will remain as vital parts of our urban areas. The problems of city centers have physical, fiscal, and social dimensions that are too difficult for government or business to solve alone. A balanced partnership between the public and private sectors can increase total effectiveness.

A balanced research agenda must be developed to (1) identify emerging phenomena that affect and result from characteristics of the built environment; (2) measure their impacts on city center functions, residents, and users; and (3) devise and prescribe policy and program packages that address the needs of diverse city centers in all parts of the nation. There is need also for a continuing assessment of research priorities and approaches and of methods for integrating the results with public policy and private decision-making processes.

*Presenter

Our report on "City Centers in Transition"* covers one of a series of five regional conferences on environmental design research needs held during June 1976, which was supported by the RANN Program of the National Science Foundation. In undertaking this conference, it was our belief that the time was ripe for focusing a new research thrust on the environmental design and revitalization of city centers.

In this brief paper, we cannot do justice to the incisive discussions and floor debates that took place during the three days when the group of 68 persons was assembled at the Quail Roost Conference Center. In our published report, however, we include the edited remarks of the final session on "Research Priorities." While all the discussion sessions have been summarized in the report, it is clear that there is no substitute for hearing or reading the actual remarks of the program panelists and the active participants in the conference. The tapes of the entire conference are on file, so that it is possible to recapture the full conference proceedings for those who were not present at the sessions. We invite you to communicate with us if you are interested in listening to any or all of the tapes for additional ideas about the revitalization of city centers, key research needs, and their public policy implications.

CONFERENCE OBJECTIVES AND QUESTIONS ADDRESSED

Specifically, this conference focused on the nerve center of the central city—the central business district or city center. The major objectives of the conference were to provide public agencies, practitioners, and the scholarly community with an improved basis for (1) identifying the critical processes and decisions that are transforming city centers; (2) evaluating the current state of the art of city center design and the match between demographic and economic processes, public and private sector decisions, and design; (3) assessing the match between the state of the art of city center design and the state of design

*Shirley F. Weiss and Raymond J. Burby, III, with Barbara G. Rodgers, *City Centers in Transition*. Report of the Environmental Design Conference Held at the Quail Roost Conference Center of the University of North Carolina at Chapel Hill, Rougemont, North Carolina, June 6-8, 1976 (Chapel Hill: Center for Urban and Regional Studies, The University of North Carolina at Chapel Hill, 1976).

practice; and (4) isolating key research needs and identifying their significance for public policy.

Five major policy questions were addressed:

(1) Will city centers—in the traditional sense—continue their historic roles as the vital cores of metropolitan areas, or, in an age of widespread decentralization, is the city center an anachronism that should be allowed to pass from the scene?

(2) What emerging trends—in population composition, economic activities, technology, design, politics, and governmental mechanisms—are shaping the functioning and physical design of city centers?

(3) In light of emerging trends, what responses from the private and public sectors are needed? How are the private and public sectors likely to respond?

(4) What is the current status of environmental design research on city centers? How can environmental design research guide adjustments in the physical environment to changing producer and consumer needs?

(5) What priorities should guide environmental design research on city centers? How can environmental design research results contribute significantly to policy decisions?

FINDINGS OF THE CONFERENCE

City centers serve important functions and will remain as vital parts of our urban areas. Although the problems of city centers—obsolescent street patterns, inadequate amenities and creature comforts, and population decentralization—have discouraged private investment in urban core areas, a latent market is present and can be captured. Much depends on the public and private response to shifting societal trends and changing federal approaches to urban problems.

It is unlikely that the central cities can amass the resources required to undertake major urban redevelopment and renewal programs. New tools, however, are emerging. These include economic rehabilitation through the designation of historic districts, homesteading of abandoned housing, assignment of public redevelopment powers to private and quasi-public organizations, creation of new institutional mechanisms, integration of housing and redevelopment programs through community development block grants, and new financing tools, such as tax increment financing, tax abatement, and tax-free bonds.

New development techniques, such as large-scale, mixed-use projects, can create a new environment downtown through the combination of highly competitive retail, restaurant, hotel, and entertainment uses in combination with commercial office space. Changes in technology can make sites, such as abandoned railroad yards, which do not require the displacement and relocation of existing populations, available for large-scale development. New technology, such as people movers, can be used to connect dispersed concentrations of activity in the downtown area.

The problems of city centers have physical, fiscal, and social dimensions that are too difficult for government or business to solve alone. A properly balanced partnership between the public and private sectors can increase the effectiveness of each. The public and private sectors must work together to achieve a sound tax program, a balanced budget that is responsive to local needs, essential public services, an improved supply of housing, increased employment and business opportunities, an improved educational system at all levels, and safety and security in the street, home, and place of business. Accomplishment of these goals will create a climate that is receptive to economic development which, in turn, can result in improved economic viability of the city itself.

Environmental design research, by its very nature is interdisciplinary in character. It is concerned with the built environment, the policies and processes involved in the creation of the environment, and the effects of the environment on its users. A number of research approaches are needed to provide the information required for the solution of problems of the built environment in city centers.

The analysis of housing problems and programs requires monitoring of the condition and characteristics of the housing stock over time. While monitoring takes the pulse of phenomena that are in process, evaluative studies are needed to measure the relative success or failure of undertakings ranging from major projects to design elements.

Policy problems of the moment require a different approach. Applied basic research involving the rigorous application of scientific methods is necessary to provide a foundation for policy analyses that can support answers which can command some degree of confidence from decision-makers.

The development of innovative, creative solutions to city center building and design problems is needed. To the extent that the public and many policymakers are not convinced of the value of a new design solution or approach unless they are able to experience it firsthand, this implies the creation of demonstration projects.

Whatever research in undertaken, it must recognize the pluralism that exists in the nation and the wide range of variation in problems and potential solutions across cities in different regions, with varying population sizes and characteristics, and varying economic, political, and spatial structures.*

RECOMMENDATIONS

A balanced research agenda must be developed to (1) identify emerging phenomena that affect and result from characteristics of the built environment, (2) measure their impacts on city center functions, residents, and users, and (3) devise and prescribe policy and program packages which address the needs of diverse city centers in all parts of the nation.

*See Appendix A for enumeration of specific research needs expressed during the "City Centers in Transition" conference.

There is a need for a continuing dialogue about research priorities and approaches and about methods of integrating the results of research with public policy and private decision-making processes. This could be accomplished by convening an annual conference on environmental design and city centers.

Information about environmental design research bearing on city centers is fragmented. Support is needed to provide for the establishment of a center for the collection, interpretation and analysis, and dissemination of information on research—past, present, and projected—on the environment of city centers, their activities, land uses, residents and users, and governance.

Finally, there is a clear need for greater sensitivity to the built environment and the forces whose interactions shape the environment over time. As a start in meeting this need, a variety of training packages could be prepared. In-service short courses dealing with the environment of city centers could be prepared for public officials and urban professionals. Curriculum packages for use in elementary and secondary schools could be developed together with a summer institute designed to instruct educators in their application. In the universities, interdisciplinary curricula and training programs could be established to begin producing future professionals who can effectively plan for and manage the complex problems of city centers and urban core areas.

ACKNOWLEDGEMENTS

The staffs of the planning departments of Chapel Hill, Durham, and Raleigh, and the Downtown Revitalization Foundation of Durham, North Carolina, Inc., assisted in arranging the tours for the three major central business districts of the Research Triangle Region. Special appreciation is due Henry J. Lagorio, Program Manager, Division of Advanced Environmental Research and Technology, RANN Program, National Science Foundation, who played a vital role in the launching of the conference, as did Jonathan B. Howes, Director, Center for Urban and Regional Studies, The University of North Carolina at Chapel Hill.

APPENDIX A

City Centers in Transition

Enumeration of Specific Research Needs

The following specific research needs were expressed during the course of the conference:

Monitoring and Evaluation: (1) Evaluation of the accomplishments and failures of public urban renewal, including the long-term impacts of renewal activities; (2) monitoring and evaluation of local housing and redevelopment activities; (3) evaluation of the real use of significant design elements, such as walkway and movement systems, in city centers; (4) evaluation of design process attributes that have produced notably successful solutions to design problems; (5) evaluation of the impact of mixed-use projects on the remainder of the city centers; and (6) evaluation of the outcomes of efforts to introduce new middle-income housing into city centers.

Revitalization Processes: (1) Specification of needed relationships between the private and public sectors in city center revitalization; (2) identification of probable private sector responses to varying kinds and levels of public investment in city centers; (3) determination of the cost-effectiveness of urban investment techniques; (4) analysis of the implications of private sector assumption of public powers, such as eminent domain, in city center redevelopment, and of private sector initiative in urban redevelopment activities; (5) specification of the costs, benefits, and risks involved in alternative public/private methods of financing redevelopment projects; (6) investigation of alternative methods of sharing the risks involved in city center investments; (7) determination of a fair rate of return for private sector investments in city centers involving various levels of risk; (8) determination of methods of informing and increasing the effectiveness of public leadership in city center revitalization; (9) analysis of how urban management systems, including zoning, permit issuance, and land acquisition can be reformed to expedite rather than hinder public and private redevelopment; (10) investigation of the use of contingency plans in center city redevelopment and revitalization programs; (11) investigation of the use of municipal budgets as economic and social policy tools: (12) development of citizen participation procedures that effectively mesh with development and redevelopment decision-making requirements; (13) identification of needed state roles in city center revitalization; (14) identification of the level and length of public commitment required to insure private sector investment in projects at various scales and periods of development; and (15) development of methods of insuring that public officials are cognizant of the social equity implications of their actions in city center redevelopment.

Housing Policy: (1) Analysis of the impacts on city centers of government policies which emphasize housing conservation and rehabilitation rather than housing production; (2) investigation of the phenomenon of restoration and rehabilitation that is occurring in central cities and analysis of how this will affect urban densities and spatial structure over time; (3) identification and analysis of the effects of historic preservation on housing for low- and moderateincome families; (4) determination of the relationship between home ownership and neighborhood commitment and stability; (5) determination of the impact of new forms of housing tenure, such as condominium ownership, on residents' housing satisfaction, long-term maintenance, and the relative ease of undertaking urban redevelopment in the future; and (6) a definitive analysis of rent control experience across a number of jurisdictions.

Social Policy: (1) Conduct of a large-scale, major analysis of public policies and programs (expanding on and going beyond the work of the Douglas Commission and Kaiser Commission) needed to improve inner city living conditions; (2) definitive analysis of the feasibility of mixing racial groups and economic classes in the same housing projects; and (3) determination of the factors required to make inner city areas attractive living environments for middle class residents.

Economic Policy: (1) Analysis of the impacts of changes in national economic conditions on local economies and

on the prospects for local economic development; (2) definitive determination of the impacts on housing production of federal monetary and fiscal policy as it affects central cities and city centers; (3) analysis of the impact of full employment on the central cities; and (4) identification of the key parameters and processes of local economic development.

In addition to these specific research needs, the conference participants felt that there is a clear need for research which would place the evolution of city centers in historical perspective. Revitalization of city centers involves management of time and change. Forces of historic precedent require careful attention, inasmuch as many of the nation's city centers have undergone a whole series of dramatic changes during the past 200 years.

Environmental Design: Discussion

QUESTION: I teach architecture and environmental design, and I have a suggestion. I would like to see a topic that covers integrative research. After going to most of the workshops at this conference, the message to me is that people are longing for design in the sense of integrating some of the separate aspects of their research. For instance, there was a workshop in which a gentleman from Colorado explained how he has been using his municipal waste as a fertilizer in an irrigation system.

Another research project was one in which a man was studying natural means of nitrogen fixation to replace or at least improve the amount of fertilizer in the world. Another man was using heat effluent from power plants to grow shrimp, and these, to me, are small indications that a lot of the researchers are looking for the connection between categories. Since this is environmental design and I think that people in this profession are really good problem solvers and see the relationships between things, I would like to see a category that speaks to this aspect. The message that I have gotten from this conference is that there is a need for an integrative design cateogry.

The second thing I have learned from going to these sessions is that a new attitude toward technology exists. A man from Davis, Califronia, was looking at how plants fix nitrogen so that we don't have to use so much energy to produce fertilizer. In general, I would say that the look at technology is not technology versus nature but learning from nature or having a technology that is less energy intensive and seeing an integration of technology with natural processes. Since the built environment is one of the major ways that we have an impact on the natural world, I think that in that same category of integrative design we could look at the relationship of the built environment to the natural environment.

MR. WILLIAMS: Your question is, did we suggest in the individual reports and the final one that integrating each individual piece of research is important, and the answer is yes, we did.

QUESTION: Mr. Williams, I note the rather conspicuous absence in the panel, and, in fact, in the discussions, of the input from the engineering profession. We didn't hear from a consulting engineer. My thoughts here go in the direction of the structural engineer who has such a powerful influence on the configuration of structures and is vitally involved in environmental design considerations. The mechanical engineer is involved in environmental considerations and interior spaces. The electrical engineer is involved in energy considerations, the illumination of interior spaces, and the illumination of exterior spaces. The acoustical engineer is involved with noise pollution and acoustics in structures. The civil engineer is involved in the utilities to serve the structures as well as the vehicular and pedestrian passageways to permit the inter-communications within urban areas. The municipal engineer himself is involved also, and there may be others.

My question is, was this an oversight or is there some other reason that the input of these design professionals didn't appear in this presentation here this morning?

MR. WILLIAMS: My background includes civil engineering. That may not answer your question, but at least it removes part of the question.

MR. LAGORIO: I think the attempt here, with these series of conferences, was really to explore the situation as seen from the perspectives of architecture, physical planning, and the physical and social sciences, to determine what areas could be examined. There were some engineers who were represented on the various conferences, and I have been continually receiving input from the engineering professions so that the final reports which are coming out of all of these sessions will include that.

I have specific recommendations from the ACSE committee on tall buildings and the role that tall buildings will play in this entire environmental design area. There are specific recommendations coming from the sensory perception aspects of the acoustics which are included, so I think in the final wrap-up of the consideration of this entire field you will find those areas which you have mentioned are quite well represented.

MR. LU: I guess a number of us come from diverse fields, myself as a planner and also as a civil engineer.

MR. LAGORIO: This is one of the characteristics of all of the conferences I attended, and it is one of the characteristics of trying to put together the identification and assessment of this field. I think this is significant and that is why I wanted to make a point of this. A number of participants had several degrees in several of the disciplines, and I think that it speaks well for the integration process. In other words, this is one way of getting a cross-section of understanding when you have people who are participating from the design professions having, in addition, degrees in some of the other areas as well.

These, to me, are some of the people who are going to hold the key to this entire area.

This is happening more and more at the universities. Joint degree programs are now possible which were not possible at one time, and I think this overall perspective is quite important.

MR. WILLIAMS: When we, in our report, talk about the environmental design professions, you will find the engineers are included.

QUESTION: I have a question about capability. In your comments, you mentioned the need to build capability, but you implied primarily manpower capability, and I would certainly agree with that, but I think there is another aspect to capability. My question is whether or not you suggested this.

Let me give you two analogies, one from agriculture and one from the space program. The Department of Agriculture has as its capability the land-grant colleges in each of the 50 states. Not only is there manpower, but also there are physical capabilities, computing capabilities, library capabilities, technician capabilities, and so forth.

In the space program, NASA, when it was faced with the problem of putting a man on the moon, consciously and deliberately set about to build up a research capability at Cal Tech and MIT. There are now over 90 schools of architecture in the United States, and I wonder if your suggestions consider the idea of building capability in terms of centers of capabilities in the schools of architecture. They could equally be analogous to the land-grant colleges in agriculture.

MR. WILLIAMS: We did not specifically say the schools of architecture, but you will find in almost every one of the individual reports and also in the summary report, a call for the setting up of geographic centers for research for several reasons. There is a need to concentrate the effort, and also a need to bring the top people together to work in the field for a while because, as you well know, it has been fragmented in the sense of a lot of us being spread all over the place.

QUESTION: I will direct this question mainly to Mr. Lu. Do you have a timetable on when information will be available for use by the local units of government? I heard you saying that you are clarifying the questions and that you will be developing information such as the psychological implications of increased housing densities. When will this type of thing be available?

MR. LU: We were asked to develop an agenda for research from the local government's point of view. We are not engaging in all of these areas of research, but we would think that this is needed. Much of this obviously depends on how NSF is going to get into this. Other federal or local governments might become involved in these things. Then we can tell what kind of a timing agenda we need. But we outline a range of research which we think is very much needed for local governments' use.

QUESTION: Do you have any idea on how long it would take to develop that if it was funded?

MR. LU: I think it is hard to tell because I haven't gone into definitions of each of these areas. This, I hope, is obviously the next step. Right now we are talking about a range of activities that are required. These obviously vary and some of these are very easy to do. I think we just simply haven't done it. Others obviously would take a longer time.

QUESTION: I certainly appreciate the information that we have received from the panel this morning and I am sure that it is extraordinarily difficult to synthesize and put everything into it, but there is one thing that has struck me very forcibly as I was listening. That is, that we are living in a man-made environment and we are discussing a man-made environment and we are looking for manpower to solve the problem.

I would suggest that maybe we ought to integrate the recommendations a little bit more particularly since most of the grants do go to men who are planning in the area. I think that it might be very well to make some special effort to say that what we need is an integrated world with women and men, a woman-and-man-made world, and we ought to look for some woman-power. I think that that might be a partial solution as far as synthesizing is concerned.

I know we are going to say that manpower is an expression which is used, but I would submit that perhaps using the expression "manpower" has more than just a language significance, and we are talking here about language.

I was wondering if indeed this did come up at any of the panels. That is, the place and the role of women and the typical job that they can do as synthesizers and the like.

DR. KAHN: Have you ever tried to make a speech in which you have to say "he or she" every time? The panel has two very talented professional women on it. Neither of them ignored the question of womanpower. I think we have got to get to more substantive issues than this. No one ignored that. We could hardly look at a "man's world" if you look at the five people up here on the panel.

QUESTION: I have an engineering question. Did you have home economists, representing some of their studies on using small houses and so on, in your conference group?

MR. LAGORIO: Yes, there were home economists. There was a conscious attempt to get many disciplines involved in all of the conferences. It may not be reflected in this panel presentation, but if a good look at all of the conference participants were taken, I am sure you would discover that all of the disciplines, as many as possible, were represented.

7

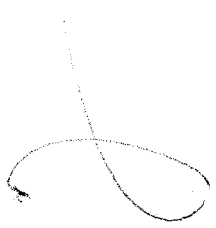
REGIONAL ENVIRONMENTAL DECISION-MAKING INFORMATION AND METHODS

7. Regional Environmental Decision-Making: Information and Methods

Four roundtable sessions focused on the regional aspects of environmental decision-making. The Hawaii Environmental Simulation Laboratory was begun in 1971 by the Oceanic Institute and the University of Hawaii, with support from the Ford Foundation. Since 1972, RANN has also provided major support for the continuation of the project. This endeavor attempts to improve environmental management through advance analysis of the implications of potential management decisions (Cox). Another effort which focuses upon potential management policies is the RANN-supported research on coastal zone management conducted by the University of Texas at Austin (Fruh). An assessment of 18 RANN projects on regional environmental systems indicated the problems users have in utilizing systems modeling projects (Mar).

Another roundtable session was devoted to environmental management strategies where two separate RANN projects were described. The first paper in this section reports on the planning and management framework for solving problems of water and land resources in the Maumee River Basin (Haimes). The second paper focuses on an analysis of a new methodology for environmental policy evaluation (Shapiro).

Roundtable Papers



Hawaii Environmental Simulation Laboratory

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The Hawaii Environmental Simulation Laboratory (HESL) was established to determine the effectiveness of an academically based but community-interactive endeavor to improve environmental management through advanced analysis of the implications of potential alternative management decisions. HESL's efforts were initially focused primarily on a single region of the island of Oahu, but some of its analyses have statewide application. Efficiency and precision of modeling were deliberately sacrificed in favor of multidisciplinary guidance with community advice, model simplicity, user-agency cooperation in model development, trial use of partially developed models, and openness to community requests for information more or less peripherally to model development. Successes are seen in the extensive community and agency use of HESL resources local contract support for specific projects supplementing Ford Foundation and NSF-RANN developmental support, and adoption of HESL models in state and county environmental regulations. Co-investigators with the author on these projects are: M. G. F. Bitterman; K. W. Bridges; K. F. Brown; T. Dinell; G. L. Dugan; P. H. P. Ho; J. C. Holmstrom; C. S. Papacostas; and D. Runyan.

The Hawaii Environmental Simulation Laboratory (HESL) was initiated in 1971 as an ad hoc endeavor to contribute to the improvement of environmental planning and management. Begun by the Oceanic Institute and the University of Hawaii with Ford Foundation support, the endeavor has been continued since 1972 by the University alone, with major support from the RANN program of the National Science Foundation as well as the Ford Foundation and supplementary support in the form of smaller grants and contracts, mostly for specific purposes, from other agencies.

Successes of the endeavor have now led to incorporation of HESL functions into the program of the Environmental Center of the University and requests for continued underwriting by the state of Hawaii through the University budget. These successes have resulted from the development of a broader focus range, and through intimate connections with the environmental decision-making elements of the community. The development involved considerable evolution of the the endeavor itself. Only a brief and selective discussion of the changes and their rationale, and of the results of the endeavor, is possible in this paper.

TOPICAL AND GEOGRAPHIC FOCUS

HESL's special interest is the environment of the Hawaiian Islands. Its concern with the improvement of the planning and management of this environment has led to a focus on those environmental aspects that are most subject to human change and those changes that are of greatest human concern. The social environment has not been excluded from HESL's concern, but among social aspects emphasis has been placed on those in which natural geographic variability is of importance.

To demonstrate the value of the endeavor as rapidly as possible, HESL's initial efforts were focused exclusively on the watersheds tributary to Kaneohe Bay on the windward coast of the island of Oahu, across the Koolau range from the major part of the city of Honolulu. However, many of the models developed by HESL for the Kaneohe region are applicable in other parts of Hawaii and elsewhere, and some of HESL's more recent efforts have had no specific relationship to the Kaneohe region.

TECHNICAL ACTIVITIES

Although recognizing that improvements in environmental planning and management required a better understanding of the complex socioecological system overall, HESL did not attempt to model the entire system

in the Hawaiian Islands, or even of the system of the Kaneohe region. Instead, HESL emphasized analyses of those subsystems in which the effects of implementing plans already adopted or proposed, or alternatives, were of greatest concern to the community.

Emphasis was placed on adaptation of existing models rather then development of new ones and use of existing data rather than collection of new data. The criteria of simplicity, as judged by potential users, and general verisimilitude, as judged by experts, were substituted for the scientific criteria of accuracy and verifiability. In the use of the individual models for simulation, computer usage, although important, became incidental, and model linkages involving subjective judgments have been deliberately left open to user choice rather than computerized.

COMMUNITY INTERACTIONS

To maximize the extent to which HESL's analytic efforts related to issues considered important in the community, and the extent to which they would actually be used in the decisions pertaining to those issues, great emphasis in the HESL endeavor has been placed on interactions with the community through various existing and ad hoc institutions.

A HESL Community Council, originally appointed by the president of the University to provide overall policy guidance to the endeavor, transformed itself into an autonomous, self-perpetuating body with a promotional as well as advisory role. Except with respect to the Community Council, however, HESL found by experience that it was much more effective to work with existing community associations and government agencies than to establish its own groups of persons influential in decision-making. Through its contacts HESL attempted to serve as an intermediary between the associations and the agencies, bringing to the attention of the agencies the concerns of the community and to the community associations, the appraisals and plans of the agencies.

Working especially with the technical staff of an agency, HESL had access to the data and models the agency was using in planning and management decisions, and in return could provide additional data supplied by the academic community, other agencies, and its own limited field work and model improvements and extensions to which the staffs of HESL, the agency, and other agencies contributed.

HESL staff working with community associations served for a time almost as staff members of these associations. However, it appeared impractical to establish and maintain relationships with community associations throughout the entire state as intimate as those it established in the Kaneohe region. Hence, HESL established a field office at the Windward Community College in the Kaneohe region, hoping that this would be maintained by the Community College as an environmental resource center and as a model for similar centers at other community colleges in the statewide university system.

Several environmental management games were adapted to Hawaiian conditions and used in the community interactive effort, some of which have been further adapted for continued use by other institutions.

HESL staff were largely responsible for the organization and operation of a workshop, involving agency personnel and representatives of the concerned community, to discuss the various proposals and implications for the future management of a small area in the Kaneohe region that included a former Hawaiian fishpond, other wetlands, and urban, resort, and park development potentials. The success of this workshop led to HESL's subsequent involvement with workshops dealing with similar planning problems in the Waipahu area of leeward Oahu and the Kona area of the island of Hawaii.

REQUEST-RESPONSE SYSTEM

HESL found that much of the community need for environmental information was site specific and required rapid response on the basis of existing knowledge rather than extensive model development. To respond effectively to this need, but also to avoid over-commitment and control the quality of the response, HESL formalized a request-response system.

All requests for information, however received, were logged in and reviewed by the staff managers. Each was classified according to its source, the nature, and extent of the response called for.

Any request that could be satisfied by HESL off-the-shelf information was responded to without question and checked off. If a request was beyond HESL's effective capabilities, it was turned down. If response could be provided more directly elsewhere, the requester was advised where he could more effectively obtain the information he wanted. To respond to any other request, one that would require some diversion from or extension of ongoing HESL technical developments, a task force was appointed. If the diversion or extension required would be substantial, the request was accepted only if substantial feedback to the HESL effort was anticipated or the requester was willing to pay for the work entailed.

In total, almost 600 requests were logged in. Only six percent of these were rejected, 47 percent were satisfied by off-the-shelf information, 29 percent by limited new work, and 16 percent by substantial new work, and only two percent remain for which responses have not yet been prepared.

Although the request-response system diverted a good deal of effort from HESL's major analytic activities, it was considered extremely useful in assuring that the analytic activities related to and produced answers pertinent to the questions of community concern. Because responses to requests requiring more than off-the-shelf information involved HESL's usual interactions, the system resulted in better community understanding of agency problems and more extensive involvement of agency personnel with community concerns.

MAJOR REQUESTS

Although HESL's activities themselves stimulated requests for HESL information, many requests would have arisen independently. Response related to some of these independent queries led to the production of some of HESL's more important reports to date.

During the period when the HESL endeavor was being planned, such concerns led the state legislature to call for the establishment of an Office of Environmental Quality Control (OEQC) in the Office of the Governor and the Environmental Center in the University. Both the OEQC and the Center have contributed to HESL's development and requested HESL attention on specific problems. The results of HESL's Kaneohe modeling activities were, for example, consolidated in a report prepared at the request of the OEQC (HESL, 1974).

In 1974, a Temporary Commission on Environmental Planning identified the concepts of carrying capaicty and overload as critical concepts in environmental planning. HESL has contributed substantially to the development of these concepts; for example, in response to a concurrent resolution of the 1974 legislature (HESL, 1975) and a request from the OEQC (Ho et al., 1976).

Such concerns, additionally, led to a 1973 legislative mandate to the State Department of Planning and Economic Development to take advantage of federal assistance in the Coastal Zone Management Program, and also led to the establishment by the counties of interim Special Management Areas as mandated by the legislature in 1975. At the request of the Environmental Center, HESL contributed substantially to the development of guidance to the counties in their establishment and management of these areas (Cox et al., 1975) and is now making the major contribution to the information systems and cartographic efforts of the long-term coastal-zone management effort, through the Pacific Urban Studies and Planning Program of the University.

SEDIMENTATION MODELING AND ITS APPLICATION

Among HESL's successes, perhaps the most easily demonstrable is the application of HESL's sedimentation hazard model. This model is based on a Soil Conservation Service model relating soil loss to rainfall, soil type, slope, vegetative cover, and control practice. In the HESL model, sediment produced is considered to have a combination of rate- and quantity dependent effects in several loci. Ratings, weightings, and simplications on the basis of best available information (mere expert opinion in some cases) produced a simple formula by which sedimentation hazard could be estimated for a particular grading project, depending on terrain and climate, location, duration of disturbance, and practices to be used.

HESL pointed out that a standard in terms of maximum permissible sedimentation hazard would imply, through the use of the formula, an appropriate limitation of combinations of grading practice and duration of disturbance; and that such a standard, though single valued, would combine desirable aspects of site dependency and developer choice. The Department of Health has incorporated this novel kind of performance standard and the HESL formula in its sedimentation regulation, and each of the counties has adopted corresponding grading ordinances.

In addition to assisting the counties in the drafting of these ordinances, HESL has prepared handbooks for each county providing instructions on the use of the sedimentation hazard formula, compilations of necessary input data, and a means for screening proposed projects so as to focus greatest attention on these that have the potential for the most severe effects.

PRODUCTS

The tangible products of the HESL endeavor include several maps of the Kaneohe region, several hundred memoranda of various lengths responding to requests, about 26 status reports, about 40 working papers, several degree dissertations, several progress reports, and some more formal publications, including those to which reference has been made as examples, whose number is still incomplete. Several of the status reports and working papers were regarded as drafts to be used in and revised through community-interactive processes. The more important of these are now being recast as technical reports for wider distribution. Two of these have now been issued. Two of the final reports due under HESL's foundation grants deal with HESL's history and the interactive process (Bitterman, 1976; Kloos and Runyan, 1976). Others in preparation will deal with watershed management, transfer possibilities, and HESL's future.

More important than these tangible products have been the greater understanding in environmental decision-making resulting from HESL's activities, although a thorough documentation of HESL's contribution can never be expected. The best demonstration of HESL's influence lies in the request for and use of HESL information by a variety of parties to solve a number of controversies, large and small, that have arisen in the Kaneohe area—not infrequently by parties taking opposite sides on the same issue. HESL's contribution to the understanding may be characterized as two-fold: a) the distinction between the objectively estimable impacts of alternative decisions and the subjective evaluation of those impacts; and b) the provision of some of the pertinent objective estimates. Significant abatement or limitation of some of the controversies appears to have resulted from HESL's contributions, but in most the effects of the contributions have been simply a better focus on the subjective value judgments.

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Methodology to Evaluate Alternative Coastal Zone Management Policies

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A multidisciplinary research team at the University of Texas at Austin was formed at the request of the Governor's Office to develop a methodology by which major impacts of proposed coastal policies could be addressed before implementation. Existing data systems and tools (interindustry economic input-output model, resource capability mapping, estuarine hydrodynamic and transport models) were incorporated within the analytical framework. With support from NSF-RANN, the utility of this approach was demonstrated to state decision-makers through application to regional problems (Coastal Bend and Lower Rio Grande Valley), subregional ones (barrier islands), and problems specific to one industry (electric utilities). Operating guidelines for state planners and research needs in terms of data acquisition and improvement of models were defined. Two other coastal states were visited to determine the applicability of transfer of the methodology as well as specific data systems and models.

Assessment of Selected Regional Environmental Systems Modeling Projects

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An assessment of 18 RANN regional environmental system projects found that users were not prepared to accept models that combined economic, engineering, and ecological aspects of such issues, that much more research was needed to generate the data and causality necessary to support these models, and that most academic teams do not provide acceptable documentation of their software. Some of the researchers argue that the goal of these projects was to demonstrate the effectiveness of interdisciplinary analysis rather than to develop software. RANN is actively evaluating the market for the software produced by the projects as well as the prescriptions suggested by the analyses completed by these projects. The projects have demonstrated a demand by local and state interests for the input data used in model development, but the demand for the output is yet to be tested.

Eighteen projects representing large-scaling interdisciplinary modeling of regional environmental systems (RES) were selected by RANN program managers for review. These projects were evaluated by reviewing documents produced by the projects, telephone or personal discussions with project personnel, and selected interviews with individuals identified by the project reports as users. In most cases, final reports were not available for examination; instead, the documents consisted of exchanges between the project and NSF program managers, project reports, and draft documents. A draft of this evaluation was circulated to the 18 project leaders for their comments prior to preparation of this report.

Most of the projects examined were scientific studies rather than applications of science. The hypothesis being tested was that analytical frameworks could be developed to assist decision-making on regional environmental issues. In most cases, the hypothesis was found to be only partially true and the project had to define more conservative hypotheses that limited the scope, detail, or number of clients. While it is desirable to establish project goals clearly, the experience with this set of projects indicated that neither the project teams, the peer reviewers, nor the RANN program managers could estimate accurately the cost in human and other resources required to reach a given RES goal.

While there is not consensus on the spatial or disciplinary scope of regional environmental analysis, Figure 1 shows the general focus of such efforts. The goal of such analysis is to examine the economic and ecological impact of land use allocation, residuals management, and interactions between rural and urban environments. To address these issues, the integration of social science methodologies (that deal with economic forces, values and perceptions, demographic factors, and employment) with engineering and planning methodologies (that deal with land use, resource consumption, production, and waste generation) and with ecologic and geographic methodologies (that deal with resource capability, ecosystem response, and resource availability) must be realized.

Using this classification, the 18 projects can be grouped into four different types. Those that addressed all three components, those that addressed the socioeconomic and technology, or technology and ecosystem, and those that addressed only one component.

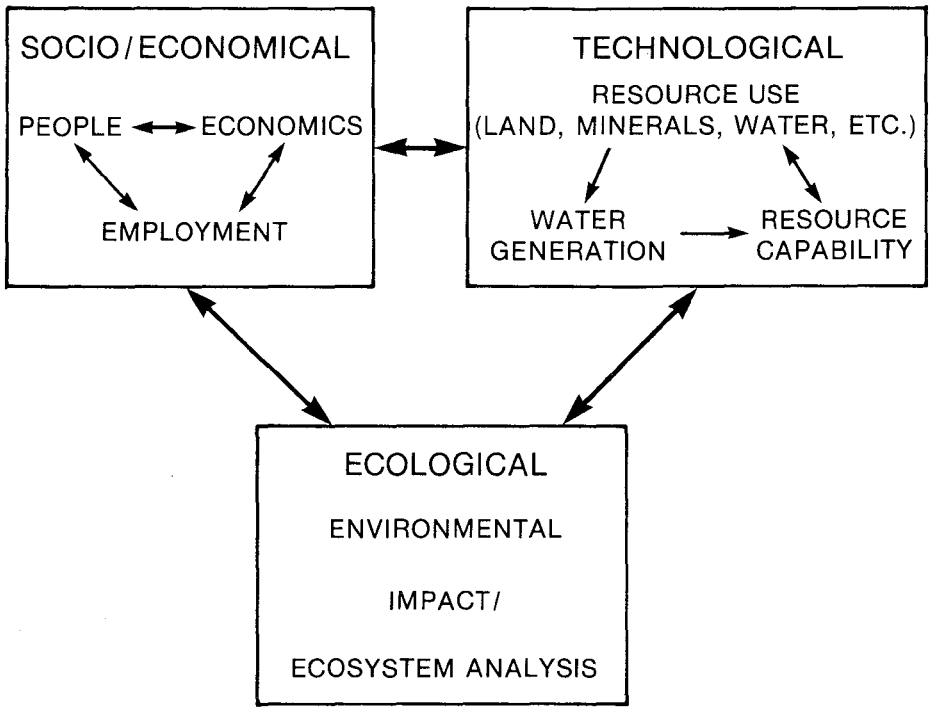

FIGURE 1.—Three major components of regional environmental system projects.

PROJECT EXPERIENCE

The process of transfer of research results was found to be the most difficult to implement, but the process of model building the most difficult to terminate. In many of the projects, model building was never completed so that transfer could not be attempted. The American Institute of Planners cautioned RANN that "experience indicates that local variability with regard to geography, ecological resources, economics and individual or institutional leadership can make large-scale transfer ability extremely difficult to achieve."[1] The projects that had the most impact on decision-making did not transfer models but worked with decision-makers to gain credibility and provide insights resulting from their modeling efforts.

In general, the user and transfer aspects of the RES projects are user specific. The tests of transferability and general usage still remain to be examined. The effort will be expensive and requires external funds. Projects do not have adequate resources to respond to inquiries let alone communicate with potential users. In contrast with transfer to the decision-making community, all projects seem to have had measurable success with transfer to the scientific community. The list of these articles and books is very large but many were not published until the end of the project. In some cases the demand for added information from the scientific community became a burden which had to be limited. Many of the documents of these projects have been reviewed and compared by disciplinary groups, but the circulation of these documents seems limited to a small number of peers. Interdisciplinary researchers and decision-makers lack knowledge and access to these documents.

While it should be possible for the originator of the computer model to work with someone knowledgeable with the computer system where the model is to be moved, some of the large models seem to contain computer-specific characteristics that impede transfer. The need to physically transfer all models is seriously questioned when the cost of developing a new model may be small compared to the cost of acquiring and manipulating data to support the model. Many of the models have unique concepts which could be useful in development of future models. It would be useful to develop a catalog of all software developed by these projects. Such an effort would require a standard format acceptable to all projects and financial resources to support such an effort. The current documentation does not permit such a catalog to be developed.

Several projects have consulting firms funded to explore the market for their models and attempt development of such markets. Since consulting firms service many regions, they may be able to identify users with similar needs and capitalize on the economics of model transfer. A few university groups have considered or actually assumed the role of consultant, but the academic pressures to seek new knowledge rather than provide consulting services are very strong. Also the time and resources required to establish such relationships with clients are very demanding on faculty resources.

Consistent with the mission of a university, the most significant product of these projects are the graduates who find employment in decision-making positions. All projects report that the project personnel have found jobs in private, local, state, and federal agencies where the modeling and interdisciplinary process can be advocated.

An analysis of the modeling strategies used by the 18 projects revealed the traditional pattern of establishing causality, identification of parameters, and then attemp-

ted validation. The unique aspects of the modeling were the interdisciplinary perspectives used to formulate the models. The introduction of an economist into an ecologist's model or vice versa, or the use of engineering philosophy in either ecological or economic models provides unanticipated perspectives.

The models developed by these projects seem to be experiments to identify simpler analytical frameworks. They provide an exhaustive test bed to explore the accuracy of simpler surrogates or methods. There is inconclusive evidence that these models are cost effective or that the cost of constructing new models rather than transferring existing ones is large compared to the data costs. The only way to determine this would be actual demonstration projects where these new methods can be compared with existing methods in field applications. It is recommended that these experiments be initiated and criteria be established to measure costs and effectiveness of these methods in RES studies. In the long run, it may be the policies or theories proved by these models that need to be transferred, not the models themselves. There is little doubt that the originating organization can modify its models to accept new data and address related problems; the difficulty is to transfer this capability to other analysts at different locations.

Projects that focused on spatially aggregated models had to invest much effort in aggregating spatial variables, a task that is often subject to much criticism. On the other hand, macro-models are much simpler to understand and transfer since they employ less regionally sensitive data.

Projects that constructed spatially disaggregated models faced a challenge to provide the level of detail and resolution desired by each potential user. They usually had to select minimum grid size and were often unable to match their data with the needs of users. These projects provided an interesting but unevaluated experience on the issue of maximum data necessary to support the analysis of specific regional environmental issues such as water quality, air quality, employment, utility development, transportation systems, schools, housing, resources use, etc. These models could not be validated because of inadequate data bases.

Many of these micro-models can be characterized as a simple formulation supported by a complex simulation procedure and a large data base. A high degree of spatial disaggregation is achieved through a fine grid and a large cellular data base containing tens of thousands of cells and 50 to 100 attributes per cell. Much of the resources of the RANN projects were devoted to perfect the data acquisition, bookkeeping, and data handling tasks that can maintain data bases used to identify parameters, formulate causality, establish constraints, and test complex models.

Each of the major components of a regional environmental system presents different data handling problems. Much of the information describing natural resources and land use is available in map form. One of the major tasks faced by most RES projects was to develop or adopt subroutines that performed a number of common map projections and would translate, rotate, scale, and even approximate projections. Another task was to develop data systems that could store, retrieve, and analyze data accumulated for each cell.

It appears that research into utilization of large data bases in construction of large models is in its infancy. One observation is that whether the entire regional issue was addressed or a small component was attacked, RANN invested similar levels of funds. If the narrow focused projects could not realize significant products, how could the broader projects?

CONCLUSIONS AND RECOMMENDATIONS

The preliminary findings of the evaluation of the RES projects indicate that a major investment is required to develop the data to support intensive large-scale modeling efforts, whether they are micro-models demanding detailed cellular data or macro-models demanding extensive time series data for parameter identification. If the trend toward the scientific/reductionist approach is to be continued, extensive investments to support data bases will be necessary. It may be several decades in the future before such data bases will be supported by federal, state, or local units of government. In the meantime, RES projects could pioneer the exploration of the use of such regional data bases. An alternative strategy is to decompose the large-scale model products into subroutines that can utilize partial data bases or respond to specific user needs.

The experiments in user involvement revealed a large gap between available knowledge and methods and those used in the decision-making arena. A very practical strategy would be to limit the next generation of RANN projects to consulting activities that emphasize the applications of existing tools to recognized problems. Since such a program would have immediate impact and the warehouse of existing knowledge seems large, such a program can have high impact, but also meet with high resistance from the scientific community that searches for new knowledge.

A third alternative is to seek to develop a new kind of science based not on full knowledge, but on the ability to cope with the unknown. Holling[2] has argued for the need to be able to fail safely rather than to develop fail-safe systems. The latter assumes full knowledge and the ability to design systems with this luxury. The former acknowledges partial knowledge and the need to be responsive and correct errors rapidly. The ability to anticipate surprises is not well developed, but Thom's catastrophe theory, Zadeh's fuzzy sets, and Shackle's surprise theory provide evidence of new alternatives to the classical data intensive reductionalist strategies. Exploration of the uncertainty and development of strategies for responsiveness and ability to perceive early warnings appear to be fruitful areas for exploration.

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Multi-Objective Analysis in the Maumee River Basin: A Case Study on Level-B Planning

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This study addresses itself to the systematic evaluation and formulation of a planning and management framework for solving the critical problems of water and land resources in the Maumee River Basin. The planning process has been carried out in complete cooperation with the Maumee River Basin Level-B Planning Board. A hierarchical multi-objective modeling and optimization structure has been developed. The Surrogate Worth Trade-off method was utilized for generating all needed Pareto optimal solutions and trade-offs as well as assisting in the selection of a preferred plan. This study was conducted under actual and real-time constraints with respect to the limitation of time, manpower, resources, and availability of adequate data and information on the Basin. The following six objectives are included in the mathematical modeling and comprehensive analysis of this study: (1) enhancement of water quality; (2) reduction of erosion, sedimentation and phosphorus from nonepoint sources; (3) enhancement of recreational opportunities; (4) protection of wildlife habitat; (5) reduction of flood damage; and (6) protection of agricultural land.

MULTI-OBJECTIVE PLANNING IN THE MAUMEE RIVER BASIN

While a great many studies related to water and land resources planning have been conducted in the past, only a handful of them have been sufficiently comprehensive in nature to integrate all the inherently complex and interacting components into a multi-objective framework. The problems of land and water resources of the Maumee Basin in particular serve to emphasize the need for such an integration if the future consequences are to be adequately considered and planned for.

A hierarchical-multi-objective modeling and optimization structure (see Haimes and Macko [1973], Haimes and Nainis [1974], and Haimes [1975 and 1977]) has been developed for adequately handling comprehensive planning in the Maumee Basin (see Figure 1). This effort is the by-product of a unique cooperative interaction between Case Western Reserve University, the Maumee River Basin Planning Board, the Great Lakes Basin Commission, the Citizens' Advisory Committee, and the other local, state, and federal agencies involved.

Initial formulation of the Level-B planning effort was based on identifying relevant goals and objectives within the Basin by the Maumee Citizens' Advisory Committee, interested citizens' groups, and other participants.

Ten major goals and objectives for the Maumee Basin Level-B planning were identified by the Maumee Citizens' Advisory Committee. They are associated with (1) land use; (2) erosion and sedimentation; (3) water quality; (4) fish and wildlife; (5) outdoor recreation; (6) flooding and drainage; (7) water supply; (8) management of Maumee Bay; (9) water and land policy; and (10) legal, institutional, and legislative aspects. In the first phase of the study, the above planning components are integrated, and an attempt is made to focus on the most critical problems in the Basin. The following six objectives are included in the mathematical modeling and comprehensive analysis of this study: (1) enhancement of water quality; (2) reduction of erosion, sedimentation, and phosphorus from nonpoint sources; (3) enhancement of recreational opportunities; (4) protection of wildlife habitat; (5) reduction of flood damage; and (6) protection of agricultural land.

A detailed development and formulation of mathematical submodels that are responsive to each of the above six major objectives and their associated constraints is given in Haimes, Das, and Sung [1977]. The assumptions and

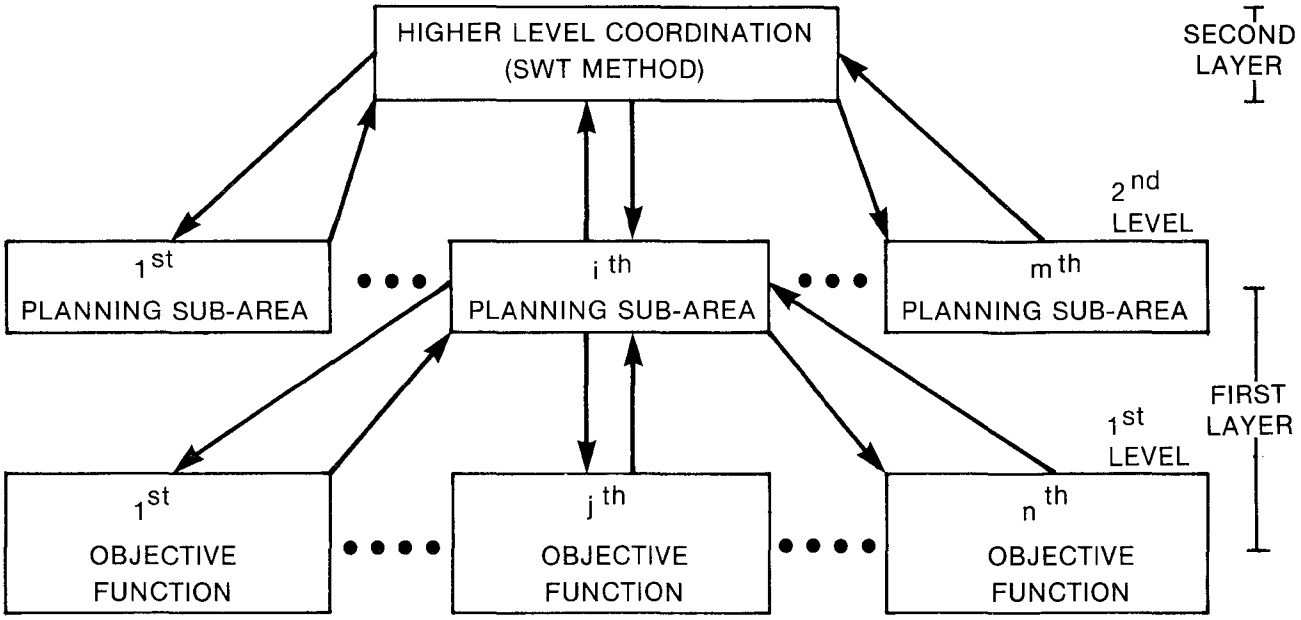

FIGURE 1—Hierarchical modeling for water resources planning.

criteria related to each of these submodels are also presented in the above report. In particular, the specific application of the submodels to the Maumee Basin is described in detail.

The hierarchical-multi-objective approach is used for integrating each of the above noncommensurable objectives to form the Integrated Multi-objective Planning Model (Haimes [1977]). Two major components of noncommensuration are identified: one relates to economic objectives and the other to environmental quality as affected by point and nonpoint source pollutants, recreation, wildlife, etc. Because of the lack of needed data and unknown critical parameter values, linear approximations are used where necessary. Nevertheless, the overall model formulation attempts to account for the complexities and dynamics of the various planning components in the Maumee Basin.

A computer program has been developed for numerical solution. The program is capable of generating alternative policies and planning activities and their associated trade-offs using the Surrogate Worth Trade-off (SWT) method. Analyses of the trade-off values and the associated level of the objective functions were carried on with the Maumee Planning Board. The implication of these trade-offs for future planning of resources in the Basin was also determined. The analysis was carried out with respect to each of the five planning subareas that are based on state and county boundaries in the Basin. The level of objectives and appropriate trade-offs among the various objectives have been determined for a range of feasible alternative plans. These plans were designated as: "environmental quality" (EQ), "miimum EQ." "economic development" (ED), "minimum ED," and a recommended plan. As inferred by name, minimum EQ places somewhat less emphasis on environmental quality, while minimum ED places less emphasis on economic development.

The report by Haimes, Das, and Sung [1977] presents an overall summary of the planning process and the applicability of the SWT method for that purpose. It also discusses the organizational and institutional setting associated with the Maumee Level-B planning and identifies the advantages and pitfalls of the associated interdisciplinary and interagency settings. A critical analysis of modeling and optimization in a water resources multiobjective planning framework is presented, focusing on the SWT method as a tool in planning. Finally, equity issues associated with the existing institutional gap between planning and implementation are given.

It is important to note that this report summarizes the completion of the first of two phases in this study which includes:

- Developing mathematical models for Level-B planning in the Maumee River Basin in complete cooperation and collaboration with the Maumee Planning Board, the study manager, and the Great Lakes Basin Commission.
- Integrating, testing, and verifying the above models, with the maximum utilization of the data base available for their use as planning tools by the Maumee Planning Board and the study manager.
- Implementing the Surrogate Worth Trade-off (SWT) method for identifying alternative Pareto optimal policies, generating trade-offs among the various objectives in each alternative, and assisting the planning board in the selection of a recommended plan for the Basin that will be submitted to the Great Lakes Basin Commission and the public.

Thus, with the selection of a recommended plan by the Maumee Planning Board, the task of the first phase of this study is essentially complete.

The objectives of the next phase of this research are to analyze the experience gained in the first phase; improve on and extend the various mathematical models developed; investigate the success of the applicability of the Surrogate Worth Trade-off method, and work toward improving it so that it becomes a more useful tool in the decision-making process when multiple noncommensurable objective functions are involved; and document the above experience for the benefit of others who are engaged with Level-B studies in particular, as well as those concerned with multiple objectives in resource planning and management in general.

THE SURROGATE WORTH TRADE-OFF (SWT) METHOD

The Surrogate Worth Trade-off method recognizes that optimization theory is usually much more concerned with the relative value of additional increments of the various noncommensurable objectives, at a given value of each objective function, than it is with their absolute values (see Haimes and Hall [1974], Haimes, Hall and Freedman [1975], Hall and Haimes [1976], Haimes and Hall [1975], and Haimes [1977]). Furthermore, given any current set of objective levels attained, it is much easier to turn to the decision-makers (DMs) to assess the relative value of the trade-off of marginal increases and decreases between any two objectives than it is to assess their absolute average values. In addition, the optimization procedure can be developed so it is no more than assessing whether one more quantity of one objective is worth more or less than that lost by another at any given level of each of them. The ordinal approach can then be used with much less concern for the distortions that relative evaluation introduces into attempts to commensurate the total value of all objectives.

One of the most important characteristics of the SWT method is that it properly leaves to the specialized analysts the quantitative-predictive (scientific) aspects of evaluation but clearly gives the decision-maker the right and responsibility for evaluating the merits of improving any one objective at the expense of any other, given the associated quantitative levels of achievement of all objectives. Because of this characteristic, the SWT method lends itself well either to simulating the likely outcome of the multiple-member decision process (given the characteristics of each DM) or to assisting the multiple-member decision group in identifying and focusing efficiently on the issues implicit in the problem's structure and public constituency.

In each such political decision process there must always be a pre-existing definition of agreement for a decision. In some cases, such as the river basin commissions, this is defined as a consensus, i.e., no one objects to the proposal (although he might vote negatively if forced to vote). In the usual case, a decision is defined by some minimum percentage majority vote. If we examine the indifference band of each member of the decision body in such a case, the ability to obtain a consensus would be reflected for those alternatives which fall within every member's bands. A majority vote requires a corresponding percentage of members' indifference bands. If no such decision (or corresponding outcome) can be found, then there is a distinct possibility that no decision can be reached without a structural modification of the proposed course of action or the rule for defining a decision.

The Surrogate Worth Trade-off (SWT) method can be used to analyze and optimize the multi-objective planning problem. A detailed discussion of the SWT method is available elsewhere [Haimes, Hall, and Freedman, 1975] and therefore only a brief summary of it is presented here:

- The SWT method is capable of generating all needed noninferior solutions to a vector optimization problem.
- The method can generate the trade-offs between any two objective functions on the basis of duality theory in nonlinear programming. The trade-off function between the i_{th} and j_{th} objective functions, λ_{ij}, is explicitly evaluated and is equivalent to

$$\lambda_{ij} = -\frac{\delta f_i}{\delta f_j}$$

- The decision-maker interacts with the systems analyst and the mathematical model at a general and very moderate level. This is done via the generation of the Surrogate Worth functions, which relate the decision-maker's preferences to the noninferior solutions through the trade-off functions. These preferences are constructed in the objective function space (more familiar and meaningful to the decision-makers) and only then transferred to the decision space. This is particularly important, since the dimensionality of the objective function space is often smaller than that of the decision space. These preferences yield an indifference band where the decision-maker is indifferent to any further trade-off among the objectives.
- The SWT method provides for the quantitative analysis on noncommensurable objective functions.
- The method is very well suited for the analysis and optimization of multiobjective functions with multiple decision-makers.
- The method has an appreciable computational advantage over all other existing methods when the number of objective functions is three or more (Cohon and Marks [1975]).

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Analysis of a New Approach for Environmental Policy Evaluation

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Paretian analysis has been developed in response to perceived limitations in traditional methods of evaluating environmental decisions. A central element of the methodology is its emphasis on the net benefits accruing to each of the parties interested in a decision. The role of the decision-maker is seen as that of balancing the interests of competing and powerful groups, each of which evaluates costs and benefits differently. The major objective of this project was to test the practicality of the technique. An interdisciplinary team of researchers used Paretian analysis to examine a series of actual environmental decisions, including air pollution, wastewater management, solid waste disposal, land use, and energy facility siting issues. These studies highlighted the usefulness of the technique in providing a framework for decision-making. A report is now being prepared to facilitate the application of Paretian analysis by decision-makers at various levels of government.

This paper describes a project to develop and evaluate a new methodology for assisting environmental decision-makers. This methodology, which was first suggested by Robert Dorfman,** has come to be known as Paretian analysis. The project is currently in its final stages of completion, and my purposes in this paper are to outline briefly the framework of Paretian analysis, to summarize the research which has been completed, and to suggest how the methodology developed would be of use to environmental decision-makers.

Paretian analysis is based upon the notion that environmental control measures are inherently redistributive; the advantages of pure air and water and the costs of attaining them are distributed to distinct groups of people whose opposing interests must be weighed and somehow reconciled. Some persons care more than others about particular features of the environment and a protection or conservation measure redistributes resources to their advantage. Protection measures revoke or diminish the longstanding rights of some people to use the environment as they wish; their welfare is reduced for the benefit of other people. In addition, the costs of environmental protection are often distributed quite differently from the benefits. These costs, in the form of taxes, user charges, and higher product prices, may be substantial. Individuals and groups therefore are concerned that the burden of environmental protection be allocated equitably, that no one escape paying a fair share of costs.

Traditional methods of formal analysis have overlooked redistributive issues, or at least relegated them to secondary importance. Cost-benefit analysis has been concerned with total benefits and costs to society, not with the benefits and costs to individual groups. More recent techniques, such as various types of multi-objective methods, have improved on the narrow framework of conventional cost-benefit analysis by analyzing a number of possibly conflicting objectives. However, again the accounting tends to subsume the interests of the separate groups affected by the decision.

In contrast, Paretian analysis focuses from the outset on identifying relevant interest groups and evaluating the impacts of possible decisions to these groups. This

*Presenter

**Dorfman, Robert, "General Equilibrium with Public Goods." Chapter 16 in *Public Economics*, J. Margolis and H. Guitton, eds. New York: Macmillian Co., 1969.

framework is based upon a set of assumptions about how an environmental protection agency operates.

PARETIAN ANALYSIS

In carrying out its work, a local environmental control agency has to alter long-established practices of industrial firms, municipalities, and other influential organizations and institutions. It must deal with relatively large and powerful units which have substantial political and legal power. Under these conditions success usually depends upon negotiation, not mandate. The decisions of the agency are usually compromises among the interests of the groups affected. Thus it is inappropriate to analyze environmental control agencies as if they were in a position to proclaim objectives and ordain compliance. Rather, the fundamental assumption of Paretian analysis is that an environmental control agency is responsive to the interests of its constituency. By building a reputation for responsiveness and fairmindedness, an agency gathers influence and political support and induces cooperation among the groups with which it must operate.

In accordance with the principal of responsiveness, the agency decisions will be of the type called "Pareto admissible." A decision is defined as Pareto admissible if there exists no possible alternative decision that some groups regard as superior and no groups regard as inferior. To the extent that this model indicates the type of decision which an environmental agency will make, Paretian analysis is a predictive model of the decision-making process. However, if the underlying assumptions about agency behavior are correct, Paretian analysis provides guidance for analysts preparing evaluations or recommendations for agency consideration: Only those alternatives which are Pareto admissible should be considered. In this sense, Paretian analysis becomes a prescriptive as well as a predictive tool for analyzing environmental issues. The goal of Parentian analysis is then to select, from among the set of technically feasible alternatives, those which are admissible. The agency must still select the final alternative, based upon its attempt to balance and reconcile the interests of competing groups. While Paretian analysis does not usually provide a single "best" decision, the information generated in the course of the analysis can be used to examine the trade-offs among individual interests.

Table 1—Steps in Applying Paretian Analysis

(1.) Definition of the decision:
- a. Boundaries of the physical system.
- b. Indices of environmental quality.
- c. Policy instruments and control measures that are to be considered.
- d. Legal, institutional, technological, and budgetary constraints.

(2.) Identification of interested parties.

(3.) Determination of the technological relations between policy instruments and indices of environmental quality.

(4.) Estimation of net benefit functions:
- a. Costs imposed.
- b. Benefits derived.
- c. Transfer payments.

(5.) Determination of the Pareto admissible decisions:
- a. Range of solutions which satisfy the criterion for Pareto admissibility.

Table 1 outlines the steps required in the application of Paretian analysis. These steps are (1) identification of the decision to be made; (2) identification of interested parties; (3) determination of the relationships between alternative control strategies and measures of environmental quality; (4) estimation of the benefit and cost functions for each interest group, taking into account transfer payments; and (5) determination of the Pareto admissible alternatives. Certain of these steps, particularly 1 and 3 are identical to those employed in conventional cost-benefit analysis. The differences between Paretian analysis and traditional methodologies emerge in steps 2, 4, and 5 where the role of interested parties is emphasized.

TESTING THE METHODOLOGY

The research conducted by the Environmental Systems Program at Harvard has utilized a series of case studies to examine the usefulness of Paretian analysis as a predictive model and as a prescriptive methodology. In each study, the five steps of analysis have been applied to a particular decision problem. Table 2 summarizes the studies which have been substantially completed. Several of these have been retrospective; we have attempted to determine whether actual environmental decisions were in accord with the Paretian model, that is, whether the final decisions reached by the agency were Pareto admissible. Like any model, Paretian analysis has imbedded in it a host of assumptions and simplifications. By subjecting the model to careful tests of its predictive ability, we hoped to examine the validity of these assumptions and simplifications.

A second set of case studies has dealt with environmental issues where no final decisions have been made. In these prescriptive studies the principal aim has been to systematically develop tools and methods for applying Paretian analysis.

Another way of classifying our case studies is by geographic region. The studies were centered primarily in two geographic areas. The Syracuse, New York, metropolitan area was the focus for case studies in air pollution control, wastewater management, solid waste management, and environmental/land use issues. The Boston, Massachusetts, region was employed for applications in regional solidwaste disposal and air quality management. An additional study on power plant siting was concerned with the entire New England region.

RESULTS

In each case where the predictive power of Paretian analysis was tested, it turned out that the actual decision of the agency was Pareto admissible when compared with alternative decisions which were or could have been considered. Also, we believe that the prescriptive studies

Table 2—Summary of Case Studies

Project	Investigators	Decision	Predictive	Prescriptive	Policy Instruments	Interested Parties	Technological Relations	Benefit Functions	Model	Potential Client
Syracuse Air Pol.	GS, HAT	Particulate Emission Levels	X		Emission Standards	Mfgrs. Gen. Pop, Govts.	Statistical Air Qual. Model, Cost-Removal Relationships	Costs	Linear Prog.	NYS DEC[1]
Syracuse Solid Waste Management	JJH, HSC, BH	Regional SWM Plan	X	X	Performance Stds., Control on Landfills, user charges	Towns	Costs for Treatment, Hauling	Costs, Area Filled	Mixed Integer Prog.	OCSWA[2]
Syracuse Regional Wastewater Management	HAT, MS, JH	Regional Wastewater Management	X		Effluent Stds., Financing Policies	Sewer Districts	Costs for Treatment, Interceptrs.	Costs	Trad. Eng'g.	OCDPW[3]
Syracuse Environmental Screening	PR, MS	Regional Land Use Plan		X	Pub. Investments, zoning, Env. Stds.	Towns	Air Qual. & Water Qual. Models, Costs for Residual Mgt.	Costs	Linear Prog.	SOCPA[4] CNYRPD[5]
Syracuse Land Use/ Environmental Infrastructure Decisions	PR, MS, RT	Regional Sewerage Investments/ Land Use in Town of Clay		X	County & Town Sewer Decisions, Financing Plan, Zoning, Effluent Standards	Land-Owners, Town of Clay	Cost of treatment, Land Development; Econometric Model of Land Value	Net Benefits, including value of land	Linear Prog.	Town of Clay, SOCPA, OCDPW
Power Plant Siting	HJ, JG	Power Plant Locations in New England		X	Formation of Regional Siting Agency	Utilities, Conservationists Local Groups, Regulatory Agencies	Costs of Capacity, Group Utility Functs. Cost-Temp. Control Relationships	Utility	Linear Prog.	Public Power Plant Siting Authorities
Solid Waste Management SRPEDD[6]	JJH, JK	Regional SWM Plan	X	X	State & Fed. Subsidies; OR & Constr. Control; Landfill regulations	Towns	Hauling, Processing (via Cost & Physical Relation); capacity limits	Costs; benefits from ultimate land-use; royalties	Mixed Integer Prog.	SRPEDD; State; Towns
Resource Recovery	JHH, JK	Regional SWM Plan including decision or use of RR		X	State & Fed. Subsidies; OR Constr. Regulations; Performance Standards	Towns; States (or other specific authorities); Private Industry	Hauling; Processing (via cost & Physical Relation); Capacity Limits; Product Specification; Net Energy Constraint	Costs; Revenues User Charges	Mixed Integer Prog.	CRRA[7] State of Mass; Towns; Private Industry; Eng'g Consultants
Air Quality Management in Boston Region	JJH, DN	Short-Term Fuels Switching Policy		X	Regs. on Fuel Switching: who? Monitoring network; demonstration of success; performance standards	Emitters	Air Qual. Standards; Fuel Costs; Probabilistic air qual. forecasting model.	Cost	Decision Analysis; Integer Prog.	EPA Regional Office; Mass. Bureau of Air Quality Control; Consultants

[1]Department of Environmental Conservation
[2]Onandaga County Solid Waste Authority
[3]Onondaga County Department of Public Works
[4]Syracuse-Onondaga County Planning Agency
[5]Central New York Regional Planning and Development Board
[6]Southeastern Regional Planning and Economic Development District
[7]Connecticut Resource Recovery Authority

demonstrated how Paretian analysis structures the investigation of a problem in a manner which is particularly appropriate for decision-makers. However, this is not to say that the applications were without difficulty. In each instance, the investigators had to deal with problems specific to the nature and technology of their problem area. In addition, some difficulties cropped up repeatedly and can be considered characteristic of the methodology rather than the specific problems.

One fundamental issue is the selection of interested parties to include in the analysis. For any significant decision there are generally a large number of groups which will be affected directly or indirectly by the action. Many groups share overlapping interests, and there is a wide divergency among groups in their extent of activity, organization, and interest in the particular issue. Care must be taken to insure that all appropriate interests are identified and represented from the outset of the analysis. But it is also true that many groups overlap to such an extent that for a particular issue they can be treated as a single interest. We have no hard and fast rules for selecting groups. Such selection must be made on the basis of familiarity with the specific problem.

In general, we were encouraged by the results of the case studies. They indicated that the insights offered by the methodology justify the additional expenditure of effort required to identify the individual interest groups and evaluate costs and benefits separately to each group. We feel that the next step in the development of the methodology should be the transfer to use by actual decision-makers.

TRANSFER OF METHODOLOGY

In the course of developing the case studies the investigators worked with environmental decision-makers in the Syracuse and Boston areas. On the basis of this experience, we feel that most experienced environmental decision-makers already have an intuitive appreciation of the principles of Paretian analysis, while lacking a more formal understanding of the methodology. To bridge this gap between theory and practice we hope to produce a final project report which decision-makers can use as a type of handbook in guiding future applications of the methodology.

ROUNDTABLE DISCUSSION

The discussion which followed this roundtable focused on the applications of multi-objective analysis to water resources and environmental problems, where the Surrogate Worth Trade-off method and the Paretian analysis were compared. Lingering issues in multiobjective optimization, in general, and the associated decision-making process were actively discussed by the participants.

8

REGIONAL ENVIRONMENTAL MANAGEMENT

8. Regional Environmental Management

Two large regional environmental management studies were considered in separate roundtables. The first roundtable addressed research conducted by Chesapeake Research Consortium on management of the physical alterations of the edges of the Bay and an evaluation of the relative impact of discrete and diffuse sources of pollutants on the quality of water in the Bay (Sullivan, Ballentine, Pheiffer, Queen, Correll).

Lake Powell, the second roundtable topic, is a man-made reservoir located in northeastern Arizona and southeastern Utah. Nine institutions have carried out 19 research subprojects that evaluate the total ecosystem surrounding and including the lake (Walther). A hydrology subproject has the responsibility of assessing water resources in the region and making these findings available to federal and state agencies, environmental groups, and planners in the region (Jacoby). Six projects are involved in direct investigation of the Lake Powell waters. Their findings and the implications of those findings to user groups are discussed in another paper included in this section (Kidd). The consequences of energy developments in the Lake Powell region on Navajo populations have been studied under six subprojects. In a final paper, a brief description and some pertinent results of each subproject will be presented (Little).

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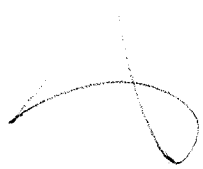
Roundtable Papers



Research Activities of the Chesapeake Research Consortium (CRC)

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NSF/RANN-supported activities of the CRC, an incorporated association of the University of Maryland, Johns Hopkins, Smithsonian Institution, and Virginia Institute of Marine Science consist of two projects. "Management of the physical alterations to the edges of Chesapeake Bay and their effects on environmental quality" has as objectives: (1) identification of patterns, trends, and rates of physical alterations and an evaluation of their environmental significance; and (2) development of a better understanding of the decision process pertaining to physical alterations and application of this understanding to the evaluation of policies and programs affecting environmental quality. Research procedures utilized include (1) selective analysis of permit applications that have been submitted to the Baltimore and Norfolk offices of U.S. Army Corps of Engineers, (2) case studies of a representative set of permit applications, and (3) shoreline studies of selected counties. "Relative impact of selected diffuse sources on quality of water in Chesapeake Bay" has as goals the development, on a regional basis, of the ability to predict: (1) water quality effects, due to diffuse sources, which are presently imposed upon waterways which drain specific watersheds; (2) changes in water quality which would occur if various changes in land use occurred; and (3) effects on water quality of tidal marshes located between drainage channels and open waters.

*Presenter

The Chesapeake Research Consortium (CRC) is an incorporated association of the University of Maryland, The Johns Hopkins University, the Smithsonian Institution, and the Virginia Institute of Marine Science. CRC was formed in 1971 to conduct interdisciplinary environmental research on the Chesapeake Bay. Research activities supported by NSF/RANN consist of two separate multi-investigator projects: (1) management of physical alterations to the edges of Chesapeake Bay and their effects on environmental quality, and (2) a quantitative study of the diffuse source loading of Chesapeake Bay.

Objectives of the physical alteration project are (1) to identify the principal patterns, trends, and rates of physical alterations of the edges of Chesapeake Bay and evaluate their environmental significance; and (2) to develop a better understanding of the decision process pertaining to physical alterations of the Bay and the application of this understanding to the evaluation of policies and programs affecting environmental quality of the region. Research procedures used in these projects include (1) selective analysis of permit applications that have been submitted to the Baltimore and Norfolk offices of the U.S. Army Corps of Engineers, (2) case studies of a representative set of permit applications; and (3) shoreline studies of selected Bay counties.

Permit analysis was undertaken to identify pattern trends and rates of shoreline alterations. Case studies of permit applications were used to (1) identify ecologic, social, economic, and legal issues presented by permit applications; (2) provide a basis for assembly and evaluation of existing literature that can be used to address these issues; and (3) develop a better understanding of the current decision process.

Shoreline studies were conducted to provide a characterization of the shoreline necessary to assess the impact of alterations activities within the shore zone. Future assessment of the environmental significance of alteration recommendations, guidelines, and criteria for managing coastal development will be based on these studies. This research has been of considerable usefulness to the Norfolk, Virginia, and Baltimore, Maryland, offices of the U.S. Army Corps of Engineers and has led to the adoption of new procedures for evaluation of permit applications.

The second project, Relative Impact of Selected Diffuse Sources on Quality of Water in Chesapeake Bay, has as its goals the development, on a regional basis, of the ability

to predict, for specific watersheds, the following: (1) The effect of diffuse sources on water quality, sources which are presently on waterways draining that watershed; (2) changes in water quality that would result if changes in land use occurred on that watershed; and (3) quantitative effects on water quality of tidal marshes located between diffuse sources of upland drainage channels and the open waters of Chesapeake Bay. These would include the removal of sediments and bacteria as well as changes in nutrient levels.

These goals are being accomplished by experimentally determining area yield loading rates for a series of pollutants from a series of land use categories in the form of land runoff (both surface and interflow). Detailed land use mapping based upon aerial photos is being carried out on two controlled watersheds. One hypothesis being tested is whether land use data and area yield loading rates for each land use category can be used to predict diffuse source loading rates. Short-term quantitative studies are in progress of runoff from a series of basins within two controlled watersheds, mapped in detail with respect to land use. These loading rates will be of considerable value to federal, state, and local management agencies in predicting estuarine diffuse source loading of various portions of Chesapeake Bay for various patterns of land use development on watersheds of the Bay.

Specific project objectives are (1) to measure total loading rates and concentrations of a series of pollutants in land runoff from a series of Bay watershed basins over a period of years; (2) to map the land use of each basin from aerial photos with respect to forest, brushlands, pastureland, fresh water wet areas, croplands, residential, roads, and tidal marshes; (3) to determine statistically valid area yield loading rates for each pollutant parameter, for each season, for each land use category (various natural, agricultural, and non-sewered, low to moderate density residential areas); and (4) to test whether land use mapping, done in sufficient detail and with sufficient accuracy but expedited by automated data processing methods, can be used as a basis for diffuse source loading estimates on larger watersheds.

Because this research has been of sufficient interest to both the Athens, Georgia, and Philadelphia, Pennsylvania, offices of the Environmental Protection Agency, the Agency has assumed management and funding of the program.

A watershed research workshop, supported by RANN, has been scheduled for February 28 to March 3, 1977, to permit publication of research findings and to allow their comparison with those from other eastern North American watershed studies.

Many of the substudies of these two projects have been completed and are documented in reports which can be obtained from the CRC Headquarters, 100 Merryman Hall, The Johns Hopkins University, Baltimore, Maryland 21218.

The Lake Powell Research Project and Some Important Air Quality Findings and Recommendations

Eric G. Walther
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Nine institutions have contributed more than 30 principal investigators to carry out the 19 subprojects on biological limnology, shoreline ecology, heavy metals, hydrology, sedimentation, lake geochemistry, physical limnology, air quality, Kaiparowits plateau resources, political science, law, epidemiology, anthropology, sociology, and economics.

We have released 19 project bulletins, have 14 others in press, and have published 37 contributions in journals. We have sponsored 24 graduate theses and have conducted three symposia.

The air around Lake Powell is superb, with visibility often over 100 miles and extremely low levels of particles, sulfur dioxide, carbon monoxide, and noise. Our theoretical models indicate the plume from the Navajo Generating Station may be causing some violations of ambient air quality standards on high terrain and may add enough mercury to Lake Powell to compare with the natural level.

AN OVERVIEW OF THE LAKE POWELL RESEARCH PROJECT

The Lake Powell Research Project (LPRP) is in the fifth year of its RANN-funded research. This project comprises over 50 scientists from the University of California-Los Angeles, Dartmouth College, University of Arizona, John Muir Institute of Environmental Studies, Utah State University, University of California-Santa Barbara, University of New Mexico, University of Rochester, and Columbia University. These scientists are studying almost every conceivable impact of the human activities around Lake Powell, created by the construction of Glen Canyon Dam on the Colorado River at the Arizona-Utah border.

The research is organized into 19 subprojects on biological limnology, shoreline ecology, heavy metals, hydrology, sedimentation, lake geochemistry, physical limnology, air quality, Kaiparowits Plateau resources, political science, law, epidemiology, anthropology, sociology, and economics.

Within these subprojects we have investigated the impacts of human activities on the quality of water in the lake and the use of water for recreation, industry, agriculture, and municipalities. At the same time, the creation of the lake had a great influence on the activities of humans, including the development of the town of Page, the construction of the 2,300 megawatt coal-fired Navajo Generating Station, and the infusion of money and job opportunities into this region. We have studied the impacts of all these changes on the Navajo Indian tribe and on political institutions involved in this region.

Although Lake Powell is the focus of the region, each study had to define its own boundary. Studies of the aquatic ecosystem made measurements within the lake, but some of the variables were influenced by streamflow from as far away as the Wind River Mountains in Wyoming and the Rocky Mountains of Colorado. Legal and political studies had to review decisions made in Washington, D.C., on the use of resources in the Lake Powell region. The air quality study had to consider the background air quality, in part determined by emissions in California, and the plume from Navajo, a power plant furnishing electricity to southern California and other urban centers.

The overall project has conducted three symposia in different parts of the West before this RANN 2 Sympo-

sium in Washington, D.C. The other symposia were conducted at a San Francisco meeting of the American Association for the Advancement of Science, a Salt Lake City, Utah, meeting of the Geological Society of America, and a Flagstaff, Arizona, meeting of our user groups.

So far, the project has released 19 bulletins, and we have 14 others in press. We have published 37 journal articles and sponsored 24 graduate theses. Besides continuing the publication of results from the subproject studies, we are also preparing 10 special integrated research reports, each one covering many disciplinary subjects. The titles of these reports are:

- Who benefits from economic development?: An estimation of local and regional expectations measured against actual economic benefits and social costs.
- The role of environmental information in natural resource decision-making in the Lake Powell region.
- Institutional decision-making and resource allocation.
- The implications for federal Indian policies of accelerated economic development of the Navajo Indian reservation.
- Impact of development on demographic structure.
- Legal and hydrologic factors in consumptive water use in the Upper Colorado River Basin.
- The Lake Powell ecosystem.
- Recreation demand and environmental quality in the Glen Canyon National Recreation Area.
- Impact of energy development around Lake Powell.
- Environmental and socioeconomic consequences of lake level decisions.

The LPRP has been successful in mobilizing and coordinating so many scientists for at least two reasons. First, the region is an exciting part of the nation with great natural beauty and resources, which nevertheless is undergoing rapid change caused by energy and recreation development. These factors make the region very interesting for scientific research. Second, the project has been guided by a steering committee of about nine scientists, chosen to cover the full spectrum of disciplines in the project. Together with two overall coordinators, one for the social sciences and the other for the natural sciences, this project leadership has proved to be both efficient and effective for such complex research and institutional arrangements.

SOME IMPORTANT AIR QUALITY FINDINGS

The air quality subprojects have measured and assembled the data from other research groups on the following air quality variables: visibility, turbidity, aerosol concentration, gas concentrations, and noise. The design of our subprojects was to only make those measurements not made by other groups, but measurements still important to develop a fairly complete picture of the air quality in the Lake Powell region.

The visibility in the region is about 116 kilometers (72 miles) on the average. This visibility ranged from 90 kilometers (56 miles) to 250 kilometers (155 miles), showing that even at its worst this region has fantastic air quality. Visibility is perhaps the most important air quality variable because it can be sensed by every person and it is critical to the recreation value of the region.

One important new source of air pollution in the region is the Navajo Generating Station. Its plume emanates from three stacks 236 meters (770 feet) in height. Casual observation has shown the plume to vary from "hard to find" to obtrusive. Measurement of the plume opacity by measuring contrast on photographic film has shown the opacity to vary from 20 to 100 percent in a stable atmosphere at distances between one and 30 kilometers downwind.

Background noise in remote locations around Page, Arizona, has been very hard to measure. Instruments are designed to measure noise, not silence. The silence can be very striking in this region. So far, our measurements lead us to conclude that the background noise is less than 20 decibels on the A-scale, a scale designed to weigh the various frequencies of sound nearly like the response of the human ear.

The mean aerosol number concentration in these remote locations is about 1,600 particles per cubic centimeter. It is compared with data from other locations in Table 1.

Table 1—Aerosol Number Concentrations

Location	Concentration (particles/cm^3)
Remote locations near Page, Arizona	1,600
Wahweap Marina, Lake Powell	6,000
Downwind of Page	9,200
Page	16,500
North Atlantic	200-500
Phoenix suburb	50,000
Busy interstate traffic	Over 1,000,000

The data in Table 1 are summarized results from many measurements made at various times of day, times of the year, and atmospheric conditions. Again, as with visibility, the cleanness of the air around Lake Powell is clear.

Another aerosol variable is mass concentration. The mass concentration is the mass of all solid and liquid particles in a unit volume of air. Some annual geometric mean concentrations are presented in Table 2.

Table 2—Aerosol Mass Concentration

Location	Year	Concentration Micrograms/n^3
Page	1969-1972	16
Page	1975	41-44
Grand Canyon	1975	14
Phoenix	1975	112-169
National secondary ambient air quality standard		60

Note the increase by a factor of at least 2.5 in the aerosol mass concentration measured at Page. This increase may be the result of several factors including a higher population, new dirt roads, more traffic, construction, and the start-up of the Navajo Generating Station Unit 1 in 1974. We cannot separate the possible contribution of these different factors.

Some nitrogen dioxide and sulfur dioxide annual arithmetic means are presented in Table 3.

Table 3—NO_2 and SO_2 Concentrations

Location	Year	Annual Arithmetic Mean Concentration $\left(\frac{Mg}{m^3}\right)$	
		NO_2	SO_2
Page	1972	8	-
Page	1973	16	-
Page	1975	5-13	1-7
Davis Dam	1972	6	-
Davis Dam	1975	11-17	-
Phoenix	1975	62-89	9-15
National primary ambient air quality standard		100	80

Despite the large emission rates of both these pollutants from the Navajo Generating Station near Page, no effect of this source can be seen in these data. All the measured concentrations in Table 3 are very low except for the substantial concentration of NO_2 in Phoenix, probably caused by the dense automobile traffic.

Our measurements of nitric oxide (NO), nitrogen dioxide (NO_2), and nitrate (NO_3) at distances of 5-55 kilometers downwind in the generating station plume in stable air have shown NO_2 concentration up to 3430 $\mu g/m^3$ and NO_3 concentration up to 14 $\mu g/m^3$.

For oxidant, the highest one-hour concentration measured in Page in 1975 was 80 $\mu g/m^3$. This is half the national ambient air quality standard and much lower than the 135-298 $\mu g/m^3$ one-hour maximum concentrations measured at various locations in Phoenix in 1975.

A few measurements of carbon monoxide in remote locations near Page indicate a background concentration near 1 milligram per m^3, much lower than the one-hour maximum concentrations of 24-49 mg/m^3 measured in Phoenix in 1975 or the one-hour national ambient air quality standard of 40 mg/m^3.

Our preliminary analysis of individual hydrocarbons shows some concentrations downwind of Page lower than those from remote locations. This finding may be caused by reactions of these hydrocarbons with nitrogen oxides emitted by cars and other combustion sources in Page.

The turbidity measurements indicate a higher turbidity coefficient at a wavelength of 500 nanometers than at 380 nanometers. This "anomalous" condition is only found at eight of 77 measuring stations located around the world. We believe water vapor and the stratospheric aerosol layer are important factors required in addition to ozone absorption and Rayleigh scattering to explain the anomaly in such clean air as is found around Lake Powell.

ROUNDTABLE DISCUSSION

The main discussion of the Lake Powell Research Project (LPRP) roundtable focused on the unprecedented effort to include a thorough social analysis of the impact of human activities in that region. According to the discussants, the LPRP was one of the very few projects to devote as much as half of its resources to social research, especially remarkable for a project initiated by natural scientists interested in geology, biology, and atmospheric science. It was observed that while social research with field data collection is quite expensive, the findings are of great interest. The project scientists were congratulated for organizing such large-scale social research between several institutions that are quite widely separated.

Hydrologic Research in the Lake Powell Region

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The purpose of the Lake Powell Research Project is to assess human activities in the Lake Powell region. The Hydrology Subproject has the responsibility of trying to answer questions relating to the water resources of the region. These water resources are crucial for energy production, agriculture, and municipal and industrial (M&I) water supply in the region and nearby population centers. Research was designed to develop methods of determining (1) effects of the Lake Powell impoundment and (2) the supply for the reservoir and thus the Upper Colorado River Basin (UCRB). The principal hydrologic perturbations due to the reservoir are surface storage, bank storage, and evaporation. Porosities and permeabilities were evaluated for the geologic formations at Lake Powell to determine bank storage. Data collection and reduction systems were established to determine evaporation losses. However, the most important aspect is supply for the reservoir and the UCRB. Dendrohydrologic techniques were applied to this question and the results give an improved estimate of renewable water supply.

The bank storage is a substantial proportion of total storage and some of it is recoverable. Net evaporation due to the reservoir can exceed 500,000 acre-feet per year at higher lake levels. The renewable surface-water supply for the UCRB is estimated to be about 13.5 million acre-feet per year, significantly less than some early estimates. These hydrologic findings can be used by federal and state agencies, environmental groups, and planners in the region.

The topics grouped under this heading include the water budget at Lake Powell and the sedimentation in Lake Powell. The water budget will be divided up into three sections: the streamflow entering Lake Powell, bank storage and evaporation at Lake Powell. Lake Powell is studied because it is the largest man-made change in the Upper Colorado River system. The reservoir started filling in March 1963, and presently contains approximately 20 million acre-feet of water in surface storage. The lake is capable of containing approximately 80 percent of the total water storage in the Upper Colorado River Basin. The water supply or the streamflow to Lake Powell is essentially the water supply for the Upper Colorado River Basin. The supply is crucial to the Southwest for agricultural use, transbasin exports, municipal and industrial water, and other uses of water in this water-deficient region.

Large surface-water storage is the main purpose of the reservoir. Power generation is a dividend that accrues when a large dam of this type is constructed. In addition to the surface storage, the major perturbations in the river system caused by this reservoir are water infiltrating into bank storage and a loss of water due to evaporation from the reservoir surface. One of the crucial variables in the lifetime of the reservoir is sedimentation influx. Information is needed about sedimentation to make estimates of the usable lifetime of the reservoir. There are many other local and regional environmental effects related to the reservoir, but they are beyond the scope of this brief presentation.

BANK STORAGE

This is important because the main function of the reservoir is water storage. Bank storage occurs in all lakes, streams, and reservoirs. It can range from being negligible up to millions of acre-feet. The questions are, is it real storage, is it recoverable, and how much is it at this reservoir?

The preliminary findings of our research indicate that the current bank storage may be approximately eight million acre-feet or about 36 percent of the total amount of water in surface-storage. This large amount is due to the geologic setting of the reservoir, primarily in porous sedimentary formations that can absorb a great deal of water. Adjacent to the lake, these formations were empty of water prior to the construction of the dam and filling of the reservoir. If one compares the increase in elevation of

the lake surface with the estimated rate at which water enters bank storage, it becomes apparent that approximately two years after a major increase in lake level there is a large decrease in the rate at which water enters bank storage. Thus, one could conclude that within two years of a major increase or decrease in lake level, there will be a tendency toward a large decrease in inflow or outflow of bank storage with the total amount changing much more slowly after this time period. The lake has almost entirely been in a filling mode since 1963. Therefore, estimates of recovery or return flow of bank storage are rather difficult. However, it appears that significant amounts of the water in bank storage could be recovered with a large decrease in lake level. An estimate of total bank storage, if the lake level were held at 3,700 feet, normal maximum pool, for several years, could reach on the order of 15 million acre-feet. However, because of the seasonal variation in streamflow and legal obligations for delivery of water downstream, it is rather unlikely that the reservoir will attain this level for that period of time. Completion of our present studies is necessary before some of these figures and conclusions can be placed on a more solid basis.

EVAPORATION

Evaporation is important because it is one of the major effects of Lake Powell, and estimates of evaporation are necessary to make estimates of bank storage. These are the two largest quantities in the water budget related to the creation of the reservoir. Evaporation is different from bank storage in that it is an annual loss that is removed from the Upper Colorado River Basin surface-water supply every year. Bank storage may take water out of the system during the filling of the reservoir, but the rate at which water enters bank storage, as previously discussed, will decrease as a quasi-equilibrium is reached between the lake and the surrounding sandstone formations.

Little can be done about evaporation; therefore there are individuals who question the value of the study. It is needed, as stated above, because it is necessary to use this information in the calculation of bank storage. Also, it is a real reservoir cost that must be considered in the design, construction, and evaluation of this type of project. Evaporation from storage reservoirs is part of the consumptive use of water in the Upper Colorado River Basin. In making estimates of the annually renewable and usable surface-water supply, evaporation must be subtracted from the total supply to arrive at a figure which is an estimate of the available supply for other consumptive uses.

The primary factors relating to evaporation are wind removing moist air from the surface of the lake and vapor pressure (which is a function of temperature) of the water at the lake surface. Mass transfer methods have been used to try to calculate the annual rate of evaporation. In the cold winter days, the evaporation may be as little as 0.05 inches per day. On a hot, windy, summer day the evaporation can be on the order of 0.5 inches per day. The annual average will approximate six feet of water per year. A preliminary energy budget has been made to estimate evaporation using this method. The energy entering and leaving the lake due to inflow, outflow, and precipitation is approximately an order of magnitude less than the energy exchange between solar and atmospheric radiation into the lake, back radiation from the lake's surface, and energy used for evaporation. These preliminary calculations also indicate approximately six feet of evaporation per year.

The concept of net evaporation must be introduced to understand the real effects of Lake Powell. It is estimated that approximately 160,000 acre-feet of water per year were lost in the stretch of river that is now inundated by Lake Powell. At approximately 3,650 feet elevation of lake surface, the total evaporation loss would be about 750,000 acrefeet per year. Thus the net evaporation, which is the real cost of Lake Powell, is about 590,000 acre-feet per year. This figure can be looked at two ways. It represents about four percent of the total surface water flow of the Upper Colorado River Basin. It also represents over 10 percent of the water available for consumptive use in the Upper Colorado River Basin. However, due to the extreme variability of wet and dry years in this arid to semi-arid climate, it is necessary to have a storage reservoir if reliable water supplies are to be available for other consumptive uses.

WATER SUPPLY

This is the most important aspect of the hydrologic research at Lake Powell. There is a finite supply for the Upper Colorado River Basin, and there are legal obligations or commitments of water to downstream users. Lake Powell is the last large reservoir in the Upper Basin. It is just above Lee Ferry, the Colorado River Compact Point, where water must be measured to determine downstream delivery of water. About 85 percent of the flow from the Upper Colorado River Basin originates in approximately 15 percent of the whole area. This 15 percent comprises the higher, rainier mountain ranges in the Upper Basin. Thus, the flow into Lake Powell is very close to the total flow for the Upper Basin. The stream gage data from the U.S. Geological Survey was reviewed to attempt to interpret what the long-term streamflow trends might be in this region. It was concluded that these records are too short for the purposes of developing long-term averages for available surface-water supply. It was concluded that the data base should be expanded and the measured flow placed in a better historical context to understand what the real water supply would be.

The method used to expand this data base was dendrohydrology. This study comprised the analysis of tree-ring width data from tree-ring sites in the Upper Basin where it was judged that the limiting factor in tree growth was moisture. Thus these trees would grow at a more rapid rate in wetter years and at a reduced rate in drier years. This moisture signal was recorded faithfully by the trees in the sites selected. The correlation coefficient between the reduced and processed ring-width data and estimates of virgin streamflow from the Upper Colorado River Basin was 0.9. With a correlation this high, it was felt that the relationship between the two sets of data was close enough that the tree-ring data could be used to recon-

struct the streamflow information. A reconstruction was made of about 450 years of streamflow. The conclusion from this 450-year reconstruction was that the early part of the 20th century was perhaps the wettest period in the entire 450 years of reconstructed streamflow. This wet period tended to inflate some of the earlier estimates of streamflow available for consumptive use in this region. The best estimate of mean annual flow based on the tree-ring studies was about 13.5 million acre-feet $\pm$ 0.5. In hearings before the passage of the Colorado River Basin Project Act of 1968, hydrologic data were reviewed in certain supportive House documents. A figure of 13.7 million acre-feet per year is used in some of these supportive documents. Thus, there is a convergence of information leading to the conclusion that the streamflow from the Upper Colorado River Basin is approximately 13.5 million acre-feet per year.

SEDIMENTATION

There has been substantial speculation about high rates of sedimentation influx into Lake Powell. The influx of sediment into a reservoir has a tremendous effect upon the life span of the reservoir. The sedimentation studies included analyses of suspended sediment data flowing into Lake Mead, into Lake Powell and past Lee Ferry before the construction of Lake Powell. Also field measurements were made by coring and precision depth-measuring devices to determine on-site amounts of sediment that had entered the lake. These studies lead to the preliminary conclusion that the sedimentation rate is on the order of 50,000 acre-feet per year. These studies indicate that the life span of the reservoir with the current influx of sediments would range from 300 to 500 years.

SUMMARY

In summary, the bank storage at Lake Powell is a large amount of water, currently on the order of eight million acre-feet. Part of it may be recoverable; however, the lake has not been lowered significantly since filling started and thus it is difficult to estimate how much would be recoverable. The evaporation is also large, approximating 10 percent of the consumptive use of water available for the Upper Colorado River Basin. Without these estimates of evaporation, it would be difficult to calculate the bank storage rate or the total bank storage. It is felt that the estimates of mean annual streamflow based on tree-ring studies produce a reliable figure for use by planners and developers in the Upper Colorado River Basin. The sedimentation studies indicate a very long life span is anticipated for Lake Powell and it will continue to function as a large storage reservoir and hydroelectric power source for a considerable time in the future.

There are projections for increased consumptive use in the Upper Colorado River Basin. The current uses are estimated at about 3.7 million acre-feet per year. Of the new uses projected, energy production is the largest single new use envisioned. Export of water from the Basin is the next largest new use anticipated, and irrigation of lands within the Basin is the third. Other consumptive uses are very small with respect to these three large projected new uses.

If one subtracts the downstream obligations of 8.25 million acre-feet per year from the 13.5 million acre-feet estimated to be available on an annually renewable basis, one concludes that the Upper Basin has 5.25 million acre-feet per year for its own use. Subtracting the 3.7 million acre-feet per year estimated as being used in 1975, the remaining water for consumptive use is about 1.5 million acre-feet. The results of the hydrologic research conducted by the Lake Powell Research Project provide federal agencies, state agencies, local and regional groups of developers, and also national and regional environmental and voting groups with information about the water resources of this region that may help them make decisions regarding future water resource development in this area.

The Physical, Chemical, and Biological Limnology of Lake Powell

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Six project areas are involved in direct investigation of Lake Powell waters. Primary sediment sources are the Colorado and San Juan Rivers. Coarser sediment fractions are deposited in deltas near confluences, and finer particles are transported further down the lake. Slumping of canyon walls has formed sediment trapping dikes across the lake bottom. Lake Powell approaches steady-state for some chemical parameters, but upper lake areas behave like a river.

Salinity and temperature profiles are available, and it is known that seasonal oxygen depletion occurs in more stable portions of the water column. Calcite precipitation is related to photosynthetic rate, and precipitation is kinetically inhibited by organics. Tamarisk invasion of the drawdown zone represents the major shoreline problem.

The lake is mesotrophic, and phosphorus is the limiting nutrient. Bacterial contamination does not affect water quality and heavy metals are derived primarily from natural erosion sources, although inputs of lead from recreational boating seem to occur. Implication to user groups will be discussed.

THE LAKE ECOSYSTEM IN TRANSITION

The answers to a number of research questions proceed naturally from viewing Lake Powell as an interacting system of physical, chemical, and biological processes. However, these processes not only respond to control by natural processes, but also to control by institutional statutes. Changes which are noted as the original Colorado River shifts to a lake may be attributed to man as well as nature. These combinations of natural and cultural affects compound the problem of understanding lake mechanics, but, on the other hand, make the research effort more fascinating.

Lake Powell is in transition from a river to a lake. Major reservoir flow still follows the original channel. We are looking at the initial phases of sedimentation, circulation patterns, oxygen patterns, salinity concentrations, and biotal distributions.

At the present time, the lake is well-mixed, oxygenated, and releases water of lower salinity than found in input waters.

Here we find recreational use as an economic asset in interaction with the inevitable environmental deterioration which accompanies use of a multiple-purpose impoundment. To asses deterioration, we need to understand the mechanics of the system. To do this, we have six projects involved in direct investigation of the lake.

THE EXPERIMENTAL SETTING

Lake Powell is about 170 miles long, over 500 feet deep, and has about 1,800 miles of shoreline. Located in northeastern Arizona and southeastern Utah and blessed with spectacular scenery comprised of deeply incised sandstone canyons, this man-made reservoir is a challenge to man's curiosity and wonderment. The lake flows through narrow canyon walls originally carved by the Colorado River.

PHYSICAL LIMNOLOGY

Major questions asked by the physical limnology group from Dartmouth College are: (1) What is the presence and extent of advective currents? (2) What are the effects of inflowing and withdrawal currents? (3) How do these factors induce circulation patterns?

Answers to these questions form the basis not only of understanding chemical and biological events within the lake, but also enable institutional managers to learn about the quality of water released downstream to Lake

Mead, the major water storage component in the lower Colorado River Basin.

Major findings of this investigation include:

- A spring overflow, which may travel the entire length of the lake, as a discrete water mass, and which forms up to 60 percent of the total inflow to Lake Powell.
- A slightly denser late summer-early fall interflow, which travels at intermediate depths. This penetration type flow is much weaker, and mixes away easily.
- A dense winter underflow current travels the entire length of the lake from December through March. This flow replenishes the bottom water, and prevents it from going anaerobic.
- The withdrawal currents in Lake Powell range about 100 feet above the level of the penstocks to 120 feet below them, depending upon the amount of water withdrawn, and to a lesser extent, the density stratification. At the normal expected operating levels of Lake Powell (elevation 3,650 to 3,700), the withdrawal zone would not be expected to entrain the surface water or the water below 3,350.
- Because of the present water routing through the body of Lake Powell (surface storage of summer waters and release of deep waters), the lake acts as a cooling basin for the Lower Colorado River System. This has resulted in a more stable year-round temperature, and a lower weighted mean average temperature for the Colorado River below the Glen Canyon Dam.
- The interaction between influent currents and withdrawal currents predicts certain seasonal advective motions, including upwelling areas, counter currents, and entrainment zones.

GEOCHEMISTRY

Major questions asked by Dartmouth College geochemists include (1) whether the lake approaches steady-state chemistry, (2) what are the temperature and salinity distributions and does oxygen become depleted in bottom waters, (3) what is the major chemical process controlling salinity within the lake, and (4) what are some specific ionic cycles within the lake.

Answers to these questions provide information to user groups that enable statements to be made regarding the quality of water released and knowledge basic to any steps toward salinity control in the Colorado River Basin.

Major findings are that Lake Powell is approaching steady-state for some chemical species, but that the upper extremities behave like a river. Salinity and temperature decrease with depth, especially in the lower reservoir. Seasonal oxygen depletion occurs in the most stable portion of the water column.

The major chemical mechanism is calcite precipitation. Photosynthesis in the surface waters raises pH level and induces calcite precipitation. Precipitation of calcite is controlled by pH, temperature, and surface area of the calcite nuclei. Interestingly, they have found that kinetic inhibition of calcite precipitation results from tannins and lignins in the waters.

Near steady-state conditions exist based on the annual configurations of sulfate, chloride, and alkalinity—particularly the latter.

Details of the silica cycle in the lake are now well understood. Silica is depleted from waters flowing downreservoir and extraction of silica is due primarily to the activity of diatoms, but there is addition of silica to the waters by dissolution of diatoms or desorption from minerals. Equilibrium and kinetics of silica desorption are now understood. Implications for lake management include (1) the fact that damming the river has resulted in a profound new control over silica—extraction by diatoms; (2) that desorption of clays attempt to raise silica levels to about 12–15 mg/liter, but diatoms extract almost all of the silica; therefore (3) river managers may reduce silica by either maximizing diatom productivity or reducing desorption by clays.

Desorption can be reduced by lowering suspended sediment concentrations and reducing the temperature of water in contact with clays.

A major purpose of the Lake Powell Project is to define processes which control water quality and the downstream impacts of water releases. Knowledge of the silica cycle adds valuable information to this objective.

SHORELINE ECOLOGY

The major question addressed by the University of New Mexico shoreline ecology investigation is the effect of fluctuating waterline on physical and biological factors above and below the shifting waterline. The research is important to public users and plays a prime role in management policy.

The research involves mapping of shoreline surface materials and correlation to vegetation, to the establishment of marginal shoreline vegetation when the reservoir water level is stabilized, and to the effect on the character of plant succession into the annual drawdown zone. Indexes of shoreline campsite carrying capacity of shoreline types are of major significance to regional planners such as the National Park Service.

Surface materials were divided into seven major types and the entire 1,800 miles of shoreline were mapped at four contours at a scale of 13 inches per mile.

The shoreline surface categories are cliff face, dome terrace, shelfy terrace, talus, alluvium, sand, and rockslide.

The predominant shoreline type is composed of cliff, talus, and rock slide. Approximately 21 percent of the available shoreline area is composed of domed terrace, a portion of which is low enough in gradient to be used for shoreline recreation. These are also the areas most readily invaded by growths of plants such as tamarisk.

The various terrace types were evaluated for plant biomass accumulation. *Tamarix pentandra* makes up the largest portion of plant biomass—877 g/100 m^2—and has the highest percent of foliage cover. Tamarisk abounds in the drawdown zone and in desirable campsite-recreation areas. Growths of this plant are reducing the desirability

of these areas for camping as well as the fact that swarms of noxious insects are associated with these plants.

A major management suggestion is that once the water elevation reaches the design elevation of 3,700 feet with a drawdown to about 3,660 feet for normal operation, control measures should be instituted in selected areas along with the planting of more desirable species such as cottonwood and Russian olive. The alternative is a dense thicket of tamarisk.

HEAVY METALS

The major objective of this investigation was to assess baseline concentrations of mercury, arsenic, calcium, cadmium, chromium, copper, iron, lead, magnesium, selenium, and zinc at Lake Powell and in water and sediments collected along major tributaries leading into the lake.

Materials for analysis included water, terrestrial vegetation, soils, sediments, aquatic microorganisms, and fish.

Major findings to date relate to the distribution of mercury in the lake and concentrations in fish tissues.

At Lake Powell, mercury is concentrated through foodchains and the sources of mercury in the system seem to come from erosion of geologic deposits. This investigation was completed prior to the start of the Navajo Generating Station at Page, Arizona. Concentrations of mercury in flesh of large walleye and large mouth bass exceed 500 ppb, but are below the standard of 1,000 ppb total mercury in fish flesh. The levels do not constitute a health hazard at this time.

In regard to levels of the other elements in fish tissues, none of the elements investigated appear to constitute a health hazard. However, selenium levels reached 17.58 mg/kg in the flesh of larger fish. High levels of 9 mg/kg have caused chronic selenosis in humans, and it has been suggested that ingestion of food containing 5 mg/kg could cause adverse effects.

Our analysis is for total selenium and it may be the selenium in the fish tissue is in a form that does not represent a health hazard. Since the mean level of selenium in edible portions of all fish was 11.79 mg/kg, it would be useful to attempt to determine the form of selenium present in the tissues.

Lead levels in gills of fish netted near a major marina in Wahweap Bay were significantly higher than levels found in gills of bass taken at Padre Bay, an area remote from marina influences. There is a possibility that recreational boating inputs of lead into the water are being taken up by the biota, but levels do not constitute a health hazard.

BIOLOGICAL LIMNOLOGY

Primary questions asked by the biological limnology investigators are: (1) What is the trophic status of Lake Powell? (2) What is the limiting nutrient? (3) Are there point sources of contamination?

On the basis of the rate of carbon fixation by phytoplankton, the lake would be classified as mesotrophic in regard to level of enrichment (trophic status). Low levels of total phosphorus and total nitrogen confirm this conclusion. Nitrogen to phosphorus ratios indicate that phosphorus is the limiting nutrient. Algal bioassay (EPA standard procedure) confirms this conclusion.

Based upon phosphorus and nitrogen inputs to the lake from natural as well as cultural sources, there are no significant inputs to the reservoir by man. Investigations of total and fecal coliform levels also confirm this conclusion.

Contributing investigators:

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Social Science and the Lake Powell Research Project

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The research findings obtained by the six subprojects of the Lake Powell Research Project (anthropology, economics, epidemiology, political science, law, and sociology) have and will continue to provide pertinent and timely information about the consequences of proposed and extant energy developments in the region.

Results indicate that state and local governments in the area are inclined to support past and future energy projects, but lack adequate means for protecting community social structures and the natural environment. Past energy projects have not contributed significantly to long-run modernization or economic growth for the permanent local populations, and future developments bring no greater promise. Economic benefits of future energy developments are unlikely to meet the expectations of indigenous Navajos and Anglos or planners and promoters. This likely result stems from several factors including the low occupational skill levels of region residents, their minimal interest in energy-related employment, and a variety of legal requirements. So long as interest rates remain high, boom/bust construction phases will characterize the proposed projects. Further, future projects could cause a substantial loss of recreational dollars to the region.

The consequences of energy developments in the Lake Powell region on Navajo populations has been studied under six subprojects: anthropology, economics, epidemiology, political science, law, and sociology. In this paper, a brief description and some pertinent results of each subproject will be given.

ANTHROPOLOGY SUBPROJECT

The Anthropology Subproject focused on two tasks: (1) the impact of rapid industrialization on local Navajo populations, and (2) Navajo tribal efforts to achieve maximum benefits from the exploitation of the reservation's extensive, but finite natural resources.

Approximately 400 detailed household interviews were conducted on Navajo heads of households living in areas affected by the construction of the Navajo Generating Station near Page, Arizona, and the Peabody Coal Company strip mine on Black Mesa. In addition, in-depth interviews were obtained with Navajo tribal leaders, and tribal documents were reviewed, especially those relating to coal mine leases and the construction of the Navajo Generating Station.

Data analysis indicates that there are marked economic and social differences between populations engaged in wage work and those engaged in traditional, rural, pastoral economies. These differences are the results of migration of younger families to the developing areas rather than to modernization of the indigenous populations. The Navajo economy has not been substantially aided by the energy developments that have occurred in the Page-Black Mesa and Four Corners area.

In spite of the energy projects, the Navajo Nation's economy is substantially undeveloped. Local Navajo populations affected by energy developments are usually uninformed (as is the tribal council) about major developments. The chairman and the general council, along with energy companies and unions, are the key decision-makers in the extraction of Navajo minerals and the employment of Navajos at the energy projects. Navajos employed in energy projects are of two types: unskilled and skilled workers who came off the reservation to obtain high-paying jobs. Except at the Black Mesa mines, both skilled and unskilled Navajos were unrepresented.

Research findings from this subproject are being utilized currently by the Navajo Office of Research and Statistics and the Bureau of Indian Affairs. Subproject data have also been used in the socioeconomic sections of

the environmental impact statement for the Exxon uranium leases.

EPIDEMIOLOGY SUBPROJECT

The Epidemiology Subproject was an effort to describe changing disease patterns on the Navajo Reservation and also demographic changes, particularly changes in fertility, both within the study areas and among other regions on the reservation.

Residents of the eastern portion of the reservation are more involved in wage work and commercial agricultural and livestock activities, whereas western residents are more dependent upon welfare and subsistence livestock raising. Economic patterns correlate roughly with morbidity and mortality patterns. In the east, the causes of morbidity and mortality are more generally of a man-made nature (e.g., accidents), whereas in the west, infectious diseases are relatively more important. Crude mortality rates are roughly the same across the reservation, but infant mortality varies widely, with relatively lower infant mortality rates in the east and relatively higher rates in the more rural west.

Fertility patterns have also been compared in the two regions. Crude fertility rates are lower in the east than in the west. Part of the explanation for this is that women in the west have a longer childbearing period than do their counterparts in the east.

Field studies in the area near Lake Powell, which follows the northwestern boundary of the reservation, have been aimed at determining the relationship between income, education, age, and family organization on the one hand and fertility behavior on the other, including age at first marriage, first pregnancy, contraceptive use, and family size. Preliminary analyses have been published as a bulletin of the Lake Powell Project.

ECONOMIC SUBPROJECT

The Economic Subproject has focused on theoretical and empirical works, on boomtown economics, and on recreational uses of areas under energy development.

The role of interest rates on construction borrowing costs was studied, showing that high interest rates force contractors to limit the time period of borrowing for labor and construction costs which, in turn, shortens the duration of a boom while increasing its intensity. The optimum path of investment in permanent and temporary capital during a boom has been illustrated and contrasted with observed patterns. Relationships of unemployment in the construction industry, geographical isolation, wage rates, lack of secondary economic development, information on boomtown living conditions, and inequities among family members have been explicated. It was found that boom areas lack adequate infrastructure developments. High wages must be paid to attract workers. It is cheaper to import necessary goods than to develop an economy that can produce these products. Thus, a boom community does not grow beyond the minimal requirements of the project involved. The result is a company town.

A historical profile of the Page, Arizona, boomtown economy has been projected with an input-output model to illustrate the roller-coaster correspondence of the economy with major local industrial payrolls and lack of secondary economic development. Some remedial measures and regional planning needs have been identified.

The impact of energy development alternatives on recreational uses has been examined, using an integrated economic model. Model components have included the local economic model for the Page area, a recreational demand equation for predicting visitation, an aesthetic damage model, a diffusion model for predicting the distribution of boats on Lake Powell, and a simple population model. It has been projected that should another power project similar to Navajo Generating Station be located near Lake Powell, it could potentially lower visitations to the Lake Powell region by 8 percent. Assuming a million visitations per year, and $25 per person per day being spent, approximately two million recreational dollars could be lost to the region. It has also been noted that increased recreation in the Lake Powell region is a result of changes in tastes, and cannot be explained by the increased incomes of the visitors. This makes forecasting future recreational rates difficult because one cannot assume that current trends will remain stable.

LAW SUBPROJECT

The Law Subproject has been concerned with two general problems: first, the extent of Navajo tribal sovereignty to govern water- and energy-related developments in the Lake Powell region, and second, the ways in which legal rules can and may affect the uses to which Colorado River water is put. Attempts have been made to identify and analyze the legal sources that define Navajo sovereignty (i.e., legislative, judicial, and bureaucratic). In addition, the relationship between these formal indices of power and the actual exercise of such power has been described.

The Navajo tribe now has the legal authority to tax non-Navajo corporations and individuals residing and/or working on the reservation. The tribe is currently concerned about the consequences of a new Navajo tax. Will such a tax merely replace the current state tax or be an additional layer of taxes? Tribal officials are uncertain about the legal and practical consequences of such a tax but are nonetheless setting up a tax commission and are planning the necessary bureaucratic structure. All of this bears directly upon the issue of Navajo self-determination. Too often the issue is viewed by non-Navajos either as a means for furthering Anglo goals, or for educating Navajos into the cultural and social traditions of the predominant Anglo society. Navajo self-determination is seldom seen by governmental agents as creating a competition with state and local governmental prerogatives. Rather, it is perceived as a method for controlling the indigenous population, and as a means by which Navajos can be separated from their scarce resources (i.e., coal, oil, clean air, and water). A major historical-legal work is in progress on the ways in which Congress, the Department of the Interior, and the Navajo tribe itself have viewed the nature of Navajo self-determination.

With respect to the second problem on legal rules affecting water uses, the Law Subproject has isolated significant ambiguities and inadequacies in the law governing the allocation of Colorado River water, including the law governing Indian water rights. It is attempting to determine how the law influences and has been influenced by often erroneous hydrological assumptions and the strain of too many potential users of too little water. Ways in which Navajo water rights have been compromised because of these forces have been studied and how state and federal law may be altered to accommodate the demands of energy producers. Current definitions of Navajo water rights are unclear and variable, changing with the political climate. Even the methods for measuring upper and lower Colorado River water flow is variable. Most importantly perhaps, the extent and means of alienating Navajo water rights is indeterminant to date, as is the issue of beneficial use of Colorado River water (Law of the River).

POLITICAL SCIENCE SUBPROJECT

Investigations of this subproject have, to date, concentrated on the implications of energy development for water resource decision-making in the Colorado Basin generally, but more specifically the Upper Basin. An assessment has been made of the posture of state and local officials toward energy development and the efforts currently being made to insure protection for both communities and the natural environment in target areas. Primary data have been gathered by conducting interviews with key figures in the decision-making process and attendance at numerous conferences held in the Rocky Mountain region regarding energy development and its implications for the region. A variety of documents have also been studied including laws, administrative decisions, planning documents, court decisions, official reports, literature provided by various interested parties, social surveys, and studies reported in the scholarly literature.

Several important findings have emerged. For example, political decision-making regarding Lake Powell and the management of the Upper Basin water supplies involves decision-makers at local, state, and international levels. The traditional mode of decision-making has involved coalition formation, state sponsorship, technical and political leadership from the Bureau of Reclamation, congressional logrolling, and federal financing of most of the project costs. This pattern persists despite challenges arising out of issues that cannot be resolved in this fashion, specifically the development or preservation of scenic sites such as Dinosaur National Monument and Grand Canyon National Park. These issues are resolved through national debates.

In contrast with past decades of interstate and interbasin conflict, the seven Basin states have forged a unified position on the issue of salinity control. Although the agreements on salinity, particularly as they concern U.S. obligations to Mexico, are considered final and definitive, there are reasons to believe these decisions are not, in fact, final. The reliance on certain levels of stream flow which may not be realized, estimates of rates of Upper Basin development that may prove inaccurate, and the efficacy of salinity control programs and projects that may or may not prove feasible may lead to new decisions. Also, the unity of the Basin is threatened by several factors: (1) the shaky premises of the salinity control program which, if its goals are not realized, could lead to international complications and domestic litigation; (2) inadequate consideration of Indian interests and inadequate machinery for Indian participation in decision-making; and (3) an unwillingness of the states to assume a significant share of the burden of the salinity control program.

Limited water supplies in the Colorado Basin imply that there must be transfers of water from agricultural to industrial use. Market mechanisms promise to provide a means for water transfers, but it is yet uncertain whether the states have the legal and/or institutional mechanisms to impose controls and conditions on transfers to achieve public policy goals protecting local communities and the environment. Upper Basin states appear disposed to facilitate energy development with varying degrees of enthusiasm and with varying degrees of concern for protecting the local communities and the natural environment. Public officials express confidence in their ability to protect these interests, but local and regional leadership institutions and legal and financial structures to assure protection appear inadequate. There has been reluctance on the part of the officials to comply with the National Environmental Policy Act (NEPA) requirements. To date, the major mechanism for insuring compliance with NEPA has been legal adjudication. However, there are two problems with such a process. First, the focus has been on the procedural requirements of NEPA, and second, there has been a failure to consider the substitutive merits of agency decisions and therefore, there has been no reform within the agencies involved. Thus, there is a gap between NEPA and the actual performance of agency decisions.

SOCIOLOGY SUBPROJECT

The Sociology Subproject undertook two major tasks: (1) to provide baseline data on multiple aspects of individual and community structures in the Lake Powell region, and (2) to analyze the past and potential changes which have occurred or will occur as a result of energy developments. Over 400 household and 100 community leader interviews were completed in one northern Arizona community and four southern Utah communities (all are population centers in this sparsely populated region). Interview schedules included standard demographic and economic items as well as attitudinal items regarding energy development and health care.

Data analysis and manuscript are incomplete. However, several findings are worthy of note. First, the rural residents in the selected communities were, at the time of the interview, overwhelmingly in favor of all forms of energy development (coal, oil, natural gas, uranium, and hydroelectric), both past and proposed. Their support for the proposed Kaiparowits power project was somewhat less than their support for the Navajo Generating Station

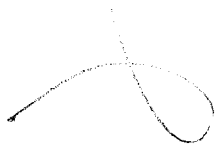
or the Glen Canyon Dam which received the greatest support.

Second, in evaluating energy projects, local residents expressed little concern for environmental degradation or potential social and political impact. Assumed economic and employment benefits stemming from proposed projects appeared to dominate their feelings in the issue. These rural residents, long underemployed and underpaid, view energy development in the Lake Powell region as an opportunity to participate in the American economic dream which has been denied them.

Third, their beliefs in the potential economic gains to be realized from energy projects are inconsistent with the likely reality. Their past economic participation in energy projects (Glen Canyon Dam, Navajo Generating Station, and various uranium and oil projects) indicates that relatively few local residents (fewer than 30%) will actually obtain employment directly with the energy firms. The vast majority of the high-paying jobs would be absorbed by skilled in-migrants from other states and regions.

Some reasons for this exceptionally limited gain in employment are (1) an unwillingness to move residences to project sites which are too distant for comfortable commuting, (2) a general lack of requisite job skills (especially in the high-skill categories), (3) an unwillingness to be trained or retrained for the skilled occupations unless critical training conditions are fulfilled, and (4) a cultural tradition of ranching and farming.

Finally, data analysis has indicated that the predominant economic flow in the study communities is for money to leave the region. As in many rural areas, purchases for durable goods, and to a certain extent, groceries, are made in larger communities out of the immediate area. In this study it was found that clothing, appliances, and automobiles were most frequently purchased at great distances from the local community, usually from 100 to 500 miles away.



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ENVIRONMENTAL RISK ASSESSMENT AND EVALUATION

9. Environmental Risk Assessment and Evaluation

Environmental decisions are made within the framework of public opinion and tax regulations. Three roundtables were organized around these areas of social and political concerns of environmental decision-makers.

The effects of federal tax policies on land use and development were considered by three authors (Peterson, Bateman, Clark). Three major research areas have been identified for improving society's ability to assess the risks of environmental hazards of human origin. These areas are explored in one co-authored paper (Kates, Rowe). The problem of introducing intangibles in environmental decisions are considered in papers which discuss environmental ethics and human value systems (Shelling, Sinden, Tribe).

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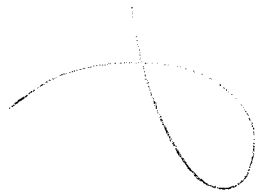
Roundtable Papers



Effects of Federal Tax Policies on Urban Land Use and Development

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The federal tax code provides perhaps the closest approximation the nation now has to an urban development policy. Federal tax policies have profoundly influenced the rate of investment in housing, relative to investment in other sectors of the American economy and consequently the physical expansion of urban areas. The tax treatment given to different types of housing expenditures has shaped the density of urban areas and the prospects for reinvestment in the central cities. The recently passed tax reform bill reflects the conviction that the structure of federal estate taxes has propelled conversion to urban uses of farmland at the urban fringe. This paper analyzes the effects of federal tax policy on the form of urban development and takes stock of what is known about the environmental and other impacts of the urban development patterns encouraged by the tax system.

Issues in Environmental Risk Assessment and Societal Response

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Risk assessment is a relatively new discipline of developing importance as society becomes more cognizant of risks inequitably imposed upon it by technological activities of man. The term risk assessment is used to describe the total process of risk analysis and amelioration of risks. The process may be divided into two parts: (1) the determination of levels of risk, and (2) the social evaluation of risks. Risk determination consists of risk (hazard) identification and risk estimation. This latter area is the most familiar area since it involves the classical methods for determining the levels of risk as well as newer techniques for modeling risk. Risk evaluation involves risk acceptance or risk aversion as alternatives to imposed risks. Risk acceptance involves determinations of acceptable levels of societal risk while risk aversion involves steps to avoid risks.

Hazard identification is particularly of interest at this time since technology has progressed to the level that many new risks are either irreversible or are of global proportions. Hazard identification is open-ended, but little attention has been given to identifying even major types of risk prior to their imposition.

Human beings appear to become increasingly adept at creating, discovering, or rediscovering threats to themselves and to their environment. A new professional interest, risk assessment, has developed to assess these hazards. Risk assessers are becoming more numerous and their products in the form of risk assessments, benefit-risk analyses, environmental impact statements, and technology assessments are widely diffused.

Through a series of recent reviews, three major research areas have been identified for improving the societal ability to assess the risks of environmental hazards. to communicate such assessments both to institutions and the public, and to act upon them. These areas relate to (1) the identification of hazards, (2) the estimation and evaluation of risks, and (3) the communication of risk assessments and related societal decision-making and policy.

Workshops are planned over the next several months in each of these areas, but already some of the major issues for research can be described.

HAZARD IDENTIFICATION

- What constitutes the set of "environmental hazards of human origin"?

Hazards are described in terms of distinctive events and their consequences. Classifications or taxonomies of hazard are derived from specific disciplines, professions, or administrative functions. Neither description of hazards or their conventional groupings seem to embrace all hazards or assist in their identification.

- What are the trends in hazard identification?

Some scattered evidence suggests an exponential increase in hazard identification, in part from the creation of new hazards or the recognition of existing ones. Establishing the seriousness of the hazard identification problem as well as strategies for societal response requires better estimates of these trends as well as their sources. Distinction between the newly created hazards, whether these exceed the rate of growth of population and wealth, and the newly recognized, whether such recognition comes from change in scientific understanding or change in societal values and expectations, needs to be

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pursued. Recent cases of "surprise" hazard identification should be studied for general lessons.

- What strategies exist for the early identification of hazards prior to suffering the consequences?

The latency and catastrophic risk of many hazards of human origin make costly dependence on consequence suffering to provide clues for hazard identification. Screening, monitoring, and diagnosis require an initial suspicion of hazard. Current and even future capacity for screening, even of known objects or processes, lags well behind their rate of creation. And the hazard potential of whole classes of objects or processes has not yet been surveyed.

ESTIMATION AND EVALUATION

- What risks are ignored or poorly estimated because the events and/or consequences are difficult to define and estimate?

There are many poorly defined "events" with potential of hazardous human consequences that are fuzzy or synergistic, not the least of which may be change itself. Mortality, morbidity, economic cost and losses, and environmental impacts are consequences commonly estimated albeit many times poorly. Psychosocial consequences are rarely estimated. Are there other classes of significant events and consequences?

- What are the best methods for approximating how safe is safe enough?

Social evaluation, the comparing and balancing of risk estimates, can be both formal and intuitive. Revealed preference methods may rely on historical record of societal "acceptance" of risk by the level of safety experienced or societal concerns reflected in media or opinion polls. Formal judgment using decision analysis or psychometric techniques with experts or publics is a second major alternative. In practice, social evaluation is informal, incremental, and intuitive.

- What makes a risk assessment "acceptable"?

Some risk assessments seem to get ready acceptance and serve as a basis for societal response with a minimum of conflict, contradiction, or doubt. Others only seem to fuel debate. Are differences in the specific hazard, the assessment content, the methods used, the judgment process employed, and the assessment communication related systematically to their acceptability?

COMMUNICATION AND DECISION-MAKING:

- Does societal response to a risk assessment differ significantly by the manner in which it is communicated?

Increasingly, risk assessments are complex scientific findings hedged with statements of probability and uncertainty and communicated through a range of private, quasi-public, and public channels. Do differences in channels and format influence societal response?

- If the trend in hazard identification is upward and perhaps exponential, how has society responded?

Societal response may take the form of increased capacity to cope with risk or in decreased attention, responding to some hazards and ignoring or giving less attention to others.

- Is there some desirable division of labor in risk assessment and societal response between market, administrative, adversary, and consensual processes of decision?

One way in which the capacity of societal response to hazards appears to be overlooked is the tendency to employ the entire spectrum of assessment and response processes for a particular hazard. Thus, repetitive risk assessments for the same hazard may be made in the economic or political market place, within administrative agencies, in the courts, and by "blue ribbon" panels and commissions. Is there some comparative advantage to each of these processes that is systematically related to the nature of the hazard or to the degree of societal concern?

ROUNDTABLE DISCUSSION

After the roundtable presentations, the following points were discussed:

- Dealing with imprecision in risk analysis and acknowledging that the perception of risk will be relatively imprecise.
- Benefits as factored into the analysis.
- Setting a policy for health protection with uncertainty in scientific risk estimates.
- Some risks, such as heavy metals in metabolism, necessary to life and regaining a balance.
- Public participation in the risk assessment process.

Human Values In Environmental Decision-Making

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One of the most perplexing tasks faced by decision-makers is weighing conflicting values, a problem particularly apparent in the environmental context. Several years ago Professor Murray Gell-Mann asked the American Academy to explore the problem of performing environmental policy analysis with adequate sensitivity to "fragile" values, such as aesthetic or intangible concerns—a problem pertinent also to many other areas of public policy. An interdisciplinary group was formed to define the questions and then to organize an inquiry into developing analytic techniques and institutional devices that would deal with value conflicts with greater sensitivity. The project was divided into two groups, one which explored the conceptual aspects of dealing with values in decision-making and the other which tested the emerging hypotheses against reality by studying the history of the Tocks Island Dam controversy, with special attention to the role of values in this environmental dispute. The results of the study, which involved frequent exchanges between the two groups, have been published in two books: a series of theoretically oriented essays, When Values Conflict, *which reflect varying perceptions of the role of values in analysis and choice, and* Boundaries of Analysis, *a case study that describes what happens to analyses and value conflicts in the real world of politics. The following is taken from the preface to* When Values Conflict.

This inquiry began in late 1970 with an initial question posed by Professor Murray Gell-Mann of the California Institute of Technology. If, as then seemed likely, a new national environmental research institute were to be established to provide analysis and guidance for policy-makers, how should it go about its work? By what methods, with what institutional arrangements, and with what kinds of intellectual resources might such an institute hope to perform its analyses with adequate sensitivity to "fragile" values, such as those of preserving wilderness and endangered species? How might such an institute hope to influence public decision-making in directions consistent with such sensitivity?

Professor Gell-Mann asked the American Academy of Arts and Sciences to sponsor several exploratory meetings to address these questions. The group organized by the Academy included individuals from many intellectual traditions, representing a range of disciplines, from the natural and social sciences to the humanities, each of which it was felt might contribute special insights into a complex problem.

What united the members of this initial planning group was not simply a fascination with Gell-Mann's question and a sense of its importance in dealing with a rapidly growing number of disputes involving the environment at the local, regional, and national levels; there was also the recognition that the difficulty of dealing with "fragile" or human values was critical for analysis and decision-making in many areas of national policy, areas as diverse as highway safety and medical ethics.

Early in our conversation, we came to the notion that the problem under discussion was at once conceptual and institutional: the analytic techniques on which an environmental institute could draw, like the legal, bureaucratic, and political framework into which its advice would have to fit, were likely to be biased against the adequate representation of some sorts of interests, values, or concerns and in favor of others, so that "hard" values, like short-term economic efficiency, would be likely to swamp "soft" values, like ecological balance, and even "softer" ones, like the love of natural beauty. We tried both to understand what made this so and to project possible remedies; to discover ways of effectively implementing what Gell-Mann provocatively described as "systems analysis with heart."

As our sessions progressed, our sense of the problem itself underwent a subtle transformation. Some of us at first, and later all of us, began to wonder just what were

the "fragile" values that we feared technological and economic analysis and political bargaining would dwarf. What was the common factor that made them difficult to address with traditional modes of analysis, originally designed to evaluate water quality, employment, and recreation needs, or the need for mass transportation? Were the professionals originally trained to consider such issues capable of dealing adequately with different ones? Were these interests given adequate weight in the decision-making process? And how was "adequate weight" to be determined?

Furthermore, we asked (and still cannot answer, as the essays in our volumes indicate) how are these values best described: as human? fragile? abstract? unquantifiable? environmental? humane? If saving whales and preserving wilderness represent "soft" concerns, in what sense are flood control, or "helping ghetto dwellers," any "harder"? And might not hard-headed economic analyses show the fool-hardiness of at least some projects that were ecologically unsound, while richer and more "humane" analyses might make some such projects seem worthwhile? It also was clear that environmental disputes frequently involve conflict between what might be considered competing "soft" values.

Thus, we began to realize that the problem we had been grappling with involved *not* a particular subset of endangered and noble values but rather the *realm of values as a whole*. It was not so much that the analytic and legal tools available to us inherently skewed policy choices toward some kinds of values and away from others (though some of us continued to find that a troubling possibility); it was that those tools, however well designed for the relatively technical task of finding suitable measures for achieving agreed-upon ends, seemed inadequate to the task of explicitly addressing controverted issues of value *at all*. Indeed, they were not designed to deal with such conflicts.

The issue before the study group that was formally organized by the Academy thus became one of understanding how analytic and institutional devices might be reshaped to address more directly the kinds of value uncertainties and conflicts that our society in the past, surer of its purposes, less nervous about the adequacy of available resources and about its own long-range prospects, and with fewer articulate interest groups, could more comfortably ignore. The analyst in these circumstances, we agreed, can rarely if ever remain quite the "neutral" scientist who eschews all value judgment; he will often be required to take a forceful role in articulating values, particularly those that seem hidden or obscure, explaining their implications and suggesting alternative and imaginative solutions to the problems in which they figure. He must ask provocative "what if" questions. In sum, it was agreed that specific recognition of the role of values and of the implications of value conflicts throughout the entire analytic and decision process would increase the probability that a society in transition could be thoughtful about its goals, most of which are not clearly perceived and may be shrouded in controversy, and could retain some measure of control over the directions in which it was moving.

To test the emerging hypotheses about analysis and values against reality, to identify a source of still further hypotheses, and to find a setting in which our conclusions might actually have significant consequences, we resolved to expand our mode of inquiry by deepening it to include the assessment of a "live" environmental dispute. The controversy over the Tocks Island Dam, still very much alive during the life of our project after over a decade of dispute and delay, was an ideal subject. A group based at Princeton University began a study of the history of this controversy and of the role values played in it, providing a common basis of data from a case in which most of the values, analytic problems, and bureaucratic processes we considered played a role. Other participants contributed conceptual and methodological insights which guided and supported the lines of inquiry in the case study. The results of the project have now been published in two volumes. *When Values Conflict* contains a series of theoretical essays on environmental analysis and decision-making; *Boundaries of Analysis* is an inquiry into the Tocks Island Dam controversy.

Both groups focus explicitly on the breakdown of discourse about questions of values we eventually came to identify as one of the central issues before us. Our ways of evaluating policy options, and our ways of implementing policy choices, cannot rise above our ways of *talking* about what is at stake and what is to be done.

In the short run we all rest most of our hopes for improvement on a more creative deployment of existing scientific and analytic resources which often can circumvent value conflict and value uncertainty by fashioning options, and perhaps even reshaping preferences, so as to satisfy seemingly irreconcilable constraints. And all of us see a major role for institutional invention.

The surfacing of unanswered questions—questions about "nature," its cultural and historic meanings, and man's relationship to it; about the place of knowledge and analysis in situations of value conflict; about the actual making of hard choices; and about the evolution of decision processes we now see as the most vital residue of our work.

Boundaries of Analysis: The Tocks Island Dam Controversy

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R. H. Socolow
H. A. Feiveson

This is a study of technical analysis in the crossfire of political controversy. Why do technical analyses so often fail to resolve issues or even to deal with what people care about most? Can we expect more of systematic thought? We find the analysis of environmental problems fragmented by a maze of criss-crossing conceptual and jurisdictional boundaries that produce narrowly constrained, piecemeal solutions that exclude important values and fit badly together. Thus, the title of our book Boundaries of Analysis *refers both to the ultimate limitations of rational analysis and to the unnecessary internal constraints that so distort public discourse. The controversy surrounding the 20-year-old proposal to build a large reservoir on the Delaware River and to surround it with a national recreation area designed for public use of unprecedented density provides an unbelievably rich tangle of minutely analyzed problems involving land use, energy, risk, beauty, individual rights, etc. which vividly illustrates the many failures of discourse in the environmental debate.*

In spite of its location in the heart of the industrial Northeast, the Delaware River is still rural, unspoiled, and unblocked by dams for most of its 300-mile length. It is seriously polluted only at its lower end near Philadelphia. The first serious attempt to put a big dam on the main stem was launched after the disastrous flood of 1955, and the effort was reinforced by the drought of the 1960s. The dam was named after a small island that it would obliterate. In accordance with custom, the project was to be multi-purpose: in addition to flood control and water supply, the reservoir was to provide a small amount of power and it was to be the center of the most intensively used National Recreation Area ever planned. Delayed by the Vietnam War, the project drifted into the era of environmental awareness of the early 1970s still unbuilt. There it encountered a spirited opposition movement which finally fought it to a standstill. At present, it lies dormant and unfunded, though Congress has so far refused to deauthorize it.

The controversy over the Tocks Island Dam involved not just one, but a whole list of environmental issues: nuclear power (a main use for the water was to cool a string of planned nuclear power plants downstream), eutrophication (would the reservoir be plagued with algae and scum like other reservoirs higher up in the basin?), traffic and explosive regional development (a whole network of new freeways was planned to handle the massive auto traffic to the recreation area), fisheries (what would happen to the oysters and shad?), archeological and historical remains (the valley contained not only early Dutch buildings but a rare and valuable archeological record dating back 10,000 years), and so forth. Over the years many of these issues had been studied and restudied, and yet it seemed to us that great gaps remained; crucial data remained uncollected, promising alternatives unexplored, and important values that people really cared about unarticulated. We aimed to illuminate, if we could, these seeming failures.

I will mention here just one or two examples. The title of our book is *Boundaries of Analysis*. In choosing this title, we had in mind not only the ultimate limitations of analysis, but also the many boundaries that cut across problems artifically and create barriers to discourse. These boundaries are of many kinds: geographical, jurisdictional, and conceptual. Because the colonists found it convenient to put political boundaries along rivers, we

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now find states and river basins cutting through one another. Thus cities (which tend to grow on both banks) and water supplies are divided between states. If the colonists had only put their state lines along watershed divides, many of today's headaches would be less painful. New York State includes a piece of the upper Delaware Basin. Consequently, New York City found it relatively easy, politically, to take clean water from the upper Delaware valley in preference to cleaning up its own Hudson water, even though the latter would have been much cheaper. Since by accident of history the upper Delaware is in New York State, the city felt that it had a special right to this water. However, in the drought of the 1960s, this decision placed New York City in direct physical competition with Philadelphia, which precipitated a tense political crisis. If each city had stuck to its own basin rather than its own state, this would not have occurred.

Another kind of boundary is the kind bureaucrats draw around their turf. Thus the Corps of Engineers in its original 1962 study failed to examine the effects of the project on regional traffic and sewage disposal because it regarded these as outside its responsibility. When these effects were later studied by the state of New Jersey, they were found to entail construction costs far in excess of the cost of the dam itself.

The most important boundaries, however, are the conceptual ones. Prime examples are the golden rules and golden numbers which seem to permeate all controversies with a technical component. These are rules and numbers that come to be accepted as constraints long after their origins have been forgotten. One notorious golden number in the Tocks Island Dam battle was 300 million gallons a day (mgd), which was supposed to be the amount of water northeastern New Jersey would some day have to take from the Delaware Basin. For years no one knew where the number came from. Finally, it was traced back through a long series of reports and water supply projections to the mid 1920s. Thus the number has recently celebrated its fiftieth or golden anniversary.

Such discourse-inhibiting boundaries are common in environmental controversies. It is the job of the non-experts, the generalists, and the informed citizens to see them and try to build bridges across them.

Summary of Roundtable Discussion on Institutional Changes To Facilitate the Incorporation of Human Values in Environmental Decision-Making

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Present environmental thought, law, and policy are based on a want-oriented perspective, on calculations of how well individual wants are satisfied. The limits of this kind of analysis are not primarily technical, but result from an ideological bias in Western society that treats human wants as the center. What is required is a new rationale for environmental policy. At the same time, a new framework for choice must be developed, an evolving process in which we grope toward a new ethic that avoids a premise of human domination. While vigorously living out the values implicit in our present stage of development; we will remain aware of the fact that these values themselves pass through evolutionary stages. A first step in this evolution, augured by the dawning of environmental awareness in contemporary culture, would be to reject human domination over other modes of being and to encourage the elaboration of felt obligations toward nature. This very process might reveal conceptual possibilities beyond our present capacities. Our choices would not merely implement but would alter our value systems, changing us as people. An alternative foundation for environmental decisions, going beyond human wants, coupled with a commitment to the groping process, would provide a structure for approaching a shared agreement about our responsibilities as persons—responsibilities to one another and to the world.

There are many ways that decision-making in all policy areas, not only the environment, can be made more responsive to certain values. Attention to the process of decision-making can be a major factor in ensuring sensitivity to often neglected interests. This emphasis on process is particularly important when one recognizes that values are not immutable, are not given once and for all, and can be changed by the consequences of our own choices.

In the effort to find effective ways of introducing values that now tend to be overlooked into the decision-making process on environmental questions and of balancing the "fuzzy" against the "harder" values, our group concluded that one promising approach was to look at institutional design.

Every decision changes the framework within which we think about our next choice, altering the values that guide us. After a decision is made to build a dam and a reservoir suitable for fresh-water sports, a certain number of people will choose to swim and boat, showing that they value these activities. But these same people, if asked before the reservoir had been created, might not at that time have placed much value on the prospective availability of fresh-water sports. Recognizing this fluidity, one goal of the contributors to this study was to encourage the development of innovative procedures that would ensure the broadest possible inclusion of divergent interests in a framework that could use this information to evaluate and compare alternative outcomes, procedures that would not simply become paralyzed when faced with a multitude of conflicting views. With this need in mind, several suggestions for institutional change were made—changes designed to create institutions and procedures that would invent and consider imaginative alternatives to conventional solutions to problems and increase the likelihood of reconciling conflicting interests.

The following summary indicates very briefly the nature of some of the suggestions for institutional change made in discussion. None of the authors gives details, but each one does give a sense of the direction in which invention might move.

Robert Socolow recommended the development of regional facilities with extensive capabilities in demographic, social, economic, and ecological data and software, available for use by interested groups. These centers would help structure improved environmental discourse, but would retain a "service" character, like the

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Library of Congress, rather than becoming generators of policy. Tools of hard science would be made available to those who wished to ask awkward "what if" questions, and in effect would consider various policy options, before deciding which one to support.

Laurence Tribe suggested that resources be devoted to working toward a new environmental ethic in several ways. In addition to improving our technical capacity to incorporate perceived obligations to nature and to objects of beauty, legislation might be enacted to permit bringing claims directly on behalf of natural objects without the requirement that such claims be couched in terms of interference with human use. We might also set aside resources and create public authorities for the specific purpose of preserving intact at least some major areas of real wilderness, while others are converted, many to Disney Worlds. In addition, Tribe suggested that efforts be made to increase the capacity of analysis to clarify the effects of choices on values typically slighted in analysis, to display vividly a multitude of perspectives for intelligent debate about the trade-offs that various alternatives involve, and, above all, to increase sensitivity to the variable ends and shifting values that the process of choice creates.

Harvey Brooks agreed that process of choice is important, and pointed out that it is this process that defines society's criteria by legitimizing outcomes. He suggested a way of synthesizing the political-participatory mode and the technocratic mode of decision-making. The first step would be to present a number of adversary analyses, with allocation of budgets for the analytic work being the responsibility of some neutral, quasi-judicial body. Then, an institution, like a technical-analytic court, with its own technical competence to deal with the various analyses would clarify and explain the choices to the various segments of the population that would be affected by the decision. This body, as an assessor of assessors, would provide a way of drawing on the strengths of both technocratic and political modes of decision. It would not, however, replace the decision-maker or decision-makers, but would evaluate the information available to them.

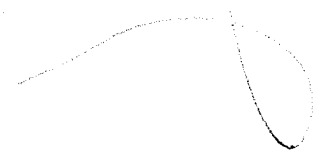
Robert Dorfman suggested an arrangement whereby funds appropriated to do a feasibility study (such as those Congress appropriated to the Corps of Engineers to study the Tocks Island case) be turned over to a Court of Environmental Affairs, rather than to one interested party. This court could invite interested groups to submit evidence of legitimate concern and after admissions had been granted, the court could divide both the budget and the tasks among them. The resulting analyses could be argued before the public and before responsible officials and agencies. No evidence which was only unilaterally available would be admissible into official proceedings and each party would have the opportunity to review and analyze each other's work.

All of these suggestions would lead toward a decision-making process that would raise the levels of public debate and broaden its terms. It is felt that these suggestions would remedy the failures of discourse about values that now inhibit the incorporation of values in environmental decision-making.

ROUNDTABLE DISCUSSION

Participants in the roundtable discussion sessions included people interested in a variety of policy areas in addition to those traditionally described as environmental. They came from the FDA, VA, GSA, and a state government science advisor's office, as well as from natural resource groups, forestry schools, public interest law groups, and from urban design and planning agencies. Their main concern was to get ideas about designing procedures or institutions which would widen effective participation in the decision-making process so as to include many interests that for reasons such as lack of money, power, or articulateness are now excluded.

Decision-making models and the concept of an environmental "situation room" were being studied by one member of the audience. Others expressed dissatisfaction with current legal arrangements for ensuring adequate representation of a wide range of values. Innovative administrative arrangements for including more views in the earliest planning phase of projects were also considered to be worth thinking about. The difficulty of accurately estimating wants or values before making policy choices and the effect of given policy choices in shaping wants and values for the future were other important recurring themes.



APPENDIX

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* Abstract only

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