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Water Resources Research and Educational Needs in Minnesota

A REPORT OF A TASK GROUP OF THE CONSULTING COUNCIL

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WATER RESOURCES RESEARCH CENTER
UNIVERSITY OF MINNESOTA
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FOREWORD

On October 5, 1965, the Consulting Council of the Water Resources Research Center established a Task Group on Water Resources Research Needs in Minnesota. The Task Group's purpose was to identify technical needs and priorities in various research and related data categories. Members of the Task Group are: G. H. Hollenstein, Minn. Dept. of Conservation, Division of Waters; R. W. Maclay, U. S. Geological Survey, Water Resources Division; M. H. Tourin, Litton Systems, Inc., Minneapolis; C. A. Van Doren, U. S. Dept. of Agriculture, Agricultural Research Service; W. C. Walton (Chairman), Water Resources Research Center; and S. Weitzman, U. S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station. The Task Group met several times during Fiscal Year 1966 to discuss research needs. People throughout the state having a vital interest in water resources research were solicited for information concerning research needs. Plans were made to hold a Conference on Water Resources Research Needs in Minnesota.

A Conference, sponsored by the Water Resources Research Center, was held November 15-16, 1966, in the North Star Ballroom, Student Center, University of Minnesota, St. Paul Campus. The Conference was planned with three major objectives in mind. One was to offer a forum to leading scientists in the water resources field from which they could express their appraisals of water resources research and educational needs in Minnesota from their respective viewpoints. Another was to provide an audience of people interested in water resources research and education in Minnesota. The third was to draw upon the audience for some indication of future water resources research and educational needs and problems. The program was subdivided into seven sections dealing with the major aspects of water resources research and education. The general pattern for each one-hour section program was a principal paper dealing with the whole subject and brief prepared statements by three persons who had read the principal paper in advance and could supplement its content. A discussion period for both speakers and audience was provided. The Conference brought together 110 people interested in Minnesota's water resources research and educational programs. Chairmen of the three sessions of the Conference were: Conrad P. Straub, School of Public Health; Landis L. Boyd, Dept. of Agr. Engr.; and Alexander Dean, Mpls. Chamber of Commerce.

Papers presented at the Conference are published in this Bulletin in the order in which they were presented. The results of a questionnaire concerning research need priorities are also summarized. This Bulletin was reviewed by speakers and the Advisory Committee and Consulting Council of the Water Resources Research Center. Without the excellent cooperation of State, Federal and private organizations and components of the University of Minnesota, the Conference and the preparation of this Bulletin would have been immeasurably more difficult.

If as a result of the Conference and this Bulletin, the Task Group is able to create an awareness of the urgent need for an accelerated water resources research and educational program as a means of stimulating the development of the economic, social, and cultural opportunities of the State; to enlist the active support of groups and individuals, including industrial, municipal, agricultural, and recreation interest in outlining and implementing an effective statewide water resources research program; and stimulate cooperation between and within government agencies at all levels, industries, colleges, universities, private organizations and others, it will consider its efforts more than justified.

WATER RESOURCES RESEARCH NEEDS

Principal Paper by William C. Walton

Water is Minnesota's most abundant natural resources; its management and use are of utmost importance. Even though our state as a whole is blessed with favorable water conditions, this does not mean that the available supply is adequate in all areas. In some sections, poor distribution of sources is a critical problem. Elsewhere, droughts and floods are reoccurring problems, and the discharge of used waters by cities and industries and erosion of soil from farm lands continues to impair our water's quality. In many parts of our state waterfowl habitats are seriously endangered because of man's activities and obnoxious aquatic vegetation, whose growth is being stimulated by pollution, is reducing the usefulness of many lakes. On the other hand, industrial expansion, new developments in agriculture, shifts and increases in population, urban requirements, and a growing interest in water-based outdoor recreation are increasing the demands for water. The problems have many implications and are generally the results of economic and social conditions caused by modern scientific and technological advances.

Industry needs water, agriculture needs water, and the people need water. Today these needs are being met, but industry, agriculture, and the population are growing--and the demand for water is growing with them. How best can future demands be met? How can there be exploitation of new water resources in areas that will overtax the existing supplies? Will the development of plans for better water storage help to alleviate the problems created by the variability of supply and demand?

WILLIAM C. WALTON graduated with a B.S. in Civil Engineering from Lawrence Institute of Technology in 1948. He attended Indiana University, University of Wisconsin, Ohio State University, and Boise Junior College of Idaho. From 1948-49 he was a Civil Engineer with the U.S. Bureau of Reclamation in Cody, Wyoming. During the period 1949-55 as a Hydraulic Engineer, he was associated with the U.S. Geological Survey in Wisconsin and Ohio. He was a Consulting Groundwater Hydrologist in Columbus, Ohio, from 1955-57. From 1957-58 he was a Hydraulic Engineer with the U.S. Geological Survey in Idaho. During the period 1958-September 1964, he was Engineer in Charge of Groundwater Research, Illinois State Water Survey. At present, he is Director of the Water Resources Research Center, University of Minnesota, and Professor of Geology and Geophysics. He is an Honorary Life Member and past Vice President of the National Water Well Association and past Editor of the Journal "Ground Water." He is a member of the Groundwater Committees of the Hydraulics Division, American Society of Civil Engineers and the Section of Hydrology, American Geophysical Union. In 1964 he was a Consultant to the Office of Science and Technology and in 1965 he was an Advisor to the United States Delegation for the Consulting Council of the International Hydrological Decade of UNESCO. He is a member of the U.S. National Committee for IHD.

Surface waters in many parts of Minnesota contain significant amounts of untreated wastes; the water is of poor quality and is unsuitable for many uses. Organic pollutants are becoming more prevalent, and natural and man-made inorganic salts have increased salinity to serious levels at places. As the population, industry, and agriculture continue to grow and prosper through the development of other available resources, the amount of polluted water could become greater while the demand for pure water continues to increase. What new methods can be devised for treating wastes before they are discharged into water supplies? How can water be reused more effectively? What constitutes an optimal use of a water supply?

Floods add to the complexities of water resources management in Minnesota. Flood control implies the prevention of river inundation and the mitigation of its effects. What can be done to insure proper planning for and construction of flood control and preventive works? What can be done to regulate flood plain occupancy? What have been and are likely to be the effects of man's activities on flood runoff?

The question of compatibility of water needs for municipal, industrial, agriculture, and recreational uses must be resolved. Our state is experiencing mounting pressure for more and better use of all surface waters for fishing, hunting, and aquatic sports. How can the two opposing doctrines be reconciled--one proposing to use all water resources to the fullest possible extent for domestic, agricultural and industrial development, and the other proposing to keep all water pristine pure? Will the state's policy be based on facts, or will unfounded prejudices play the dominant role? How can the optimization of water benefits be made without destroying the socio-economic structure of individual communities?

Satisfactory answers cannot be given to the foregoing questions without a great deal of additional research in the physical, biological and social aspects of water resources. Only through research, a continuous outreach for facts, can the needed analytical tools be developed and the present inadequate limits of knowledge be surpassed to give Minnesota practical solutions to its water problems. Our state has need for new concepts and new water resources research attitudes.

Success in solving our state's water resources problems will require coordination of the research efforts of colleges and universities, private and industrial groups, and agencies of government. In developing an adequate research program, we will be confronted with two major constraints: research funds will be relatively limited and good research people will be difficult to find. All available research talent will have to be fully utilized--no one organization or discipline will provide the needed specialists. Research programs directed toward the physical aspects of the occurrence, movement, and utilization of water resources will have to be accompanied by an equally vigorous attack on the biological and social science problems. Water resources research will have to be approached on an interdisciplinary basis.

To my knowledge, there is no accurate data available as to the total present expenditures for water resources research in Minnesota. However,

most of the research is probably financed by the Federal Government as is generally the case throughout the Nation. The total budget of the Federal Government for water resources research for the 1966 fiscal year was approximately $92 million. Current Federal expenditures for water resources research are less than one per cent of the estimated annual investment in water facilities of around $12 billion. Current state expenditures for water resources research are probably only a small fraction of one per cent of the annual investment in water facilities in Minnesota. Many industrial enterprises spend seven or eight per cent or more of their total volume of business on research and development. It would seem appropriate that the state greatly increase its expenditures for water resources research.

A report prepared by the Federal Council for Science and Technology and transmitted to Congress by President Johnson in March 1966, "A Ten-Year Program of Federal Water Resources Research," recommends a doubling of the Federal water resources research effort by 1971. In terms of recommended percentage increase in research effort water quality control was high with a proposed 17 fold increase; followed by techniques of planning 12 fold; evaluation process 10 fold; cost allocation, cost sharing, pricing and repayment 10 fold; and water law and institutions 10 fold. The 88-page report further states, "Possibly the most promising area of research in terms of immediate and long-term payoff is the area dealing with the methodology and criteria for water resources planning. Yet this area can be described as the most neglected area in the present research program." Areas of research needs in water resources planning were classified into seven categories as follows:

Techniques of planning--application of systems analysis to project planning; treatment of uncertainty; probability studies.

Evaluation process-development of methods, concepts and criteria for evaluating project benefits; discount rate; project life; methods for economic, social and technological projections; reliability of projections; research on the value of water in various uses.

Cost allocation, cost sharing, pricing/repayment--research on methods of calculating repayment and establishing prices for vendible products; techniques of cost allocation; cost sharing, pricing and repayment policy.

Water demand--research on the water quantity and quality requirements of various uses, both diversion and consumption.

Water law and institutions--a study of state and Federal water law looking to changes and additions which will encourage greater efficiency in use; investigation of institutional structures and constraints which influence decisions on water at all levels of government.

Nonstructural alternatives--exploration of methods to achieve water development aims by nonstructural methods such as flood plain zoning.

Ecologic impact of water development--effects of water management operations on overall ecology of the area.

The report also gave high priority to research in water quality management and protection. This area of research includes identification of pollutants, sources and fate of pollution, effects of pollution, waste treatment processes, ultimate disposal of wastes, water treatment, and water quality control. Other recommendations concerning research needs stressed in the report are:

A program of research on methods of conserving water in industry and municipal use should be initiated at once. In particular, steps which reduce the use of water for waste carriage should be intensively studied, both as means for saving water and reducing pollution of streams and lakes.

Research on methods of conserving water in agriculture should be accelerated.

A program of research on the possible ecologic impacts of water development should be developed in order that probable impacts can be introduced in future project planning.

Research on the evaluation of the effect of certain nonwater activities on water should be undertaken. The most pressing problem in this category is the effect of urbanization and this should receive first priority. The research should be aimed at devising methods of avoiding undesirable effects.

Research on evaluating climatic changes and the significance of fluctuations from flood to drought should be prosecuted vigrously.

The University of Minnesota in September 1964 took an important step towards assisting our state in solving its water resources problems by establishing in the Graduate School a Water Resources Research Center. The Center supports basic and applied research and advanced education in water resources and presents a unique interdisciplinary program for water resources research in the biological, physical, and social sciences. It focuses on the myriad aspects of a water problem--cuts across the usual disciplinary boundaries to draw upon diverse resources to solve a particular problem. Thus, the nature of the problem determines the methods of solution without categorical limitations. The Center identifies research problems, encourages interested faculty and students to engage in water resources research, coordinates the work of experts from diverse disciplines, and facilitates cooperation among the various University Schools, Departments and Divisions. The Center recognizes its responsibility as an integral part of an educational institution to prepare today's students to be tomorrow's water resource leaders in management, planning, scientific and social research, and engineering. During fiscal year 1966 the Center supported 14 water resources research projects involving 16 faculty members and 38 undergraduate and graduate students in 9 Departments within the University. Most of the research was supported with funds (about

$150,000) made available through the U.S. Department of the Interior, Office of Water Resources Research in connection with the Water Resources Research Act of 1964. The University of Minnesota through the Center has demonstrated its interest and its capability and it is willing to further develop a truly outstanding water resources research facility for Minnesota. It could provide the mechanism for unifying water resources research throughout our state.

RESEARCH ON WATER SUPPLY

Principal Paper by Richmond F. Brown

Just about one year ago the Task Group of the Consulting Council of the Water Resources Research Center to study research needs relative to the water resources in Minnesota met to itemize those research needs that seem most critical for Minnesota. Both applied and basic research on principles and processes were considered. Of the seven single spaced pages that were listed as separate one or two line items for research, approximately one half were concerned with groundwater supply. My original intent was to list many of these and explain why they were needed. But the fact is that it is unlikely that either funds or personnel will be available to do any significant part of this needed research during the next several years. Accordingly, what I propose to do is to list and justify those high priority items of research that must be accomplished within a short period of time.

Probably few people will question why research is needed in groundwater hydrology at the present time. We have been bombarded by statements from newspapers, radio, television, all saying that one of our critical problems is water. Obviously, in order to solve the critical problems that must exist around us, we need answers that only research can supply. Nevertheless, for some people in Minnesota, land of some 14,000 lakes, it is difficult to visualize the critical need for water research. It is apparent that most towns in Minnesota now have or can get adequate supplies of water for the foreseeable future. What then is the principle problem? As I see it, the principle problem is the economic utilization of available water supplies. The question is not whether one can get water supplies at a given place, the question is where should one go in order to get the most economic supplies and what yields can one anticipate from these sources? When we phrase the question this way, it becomes apparent that in Minnesota, we have not the needed knowledge to describe all the alternative solutions to a water-supply problem.

RICHMOND F. BROWN took his training in geology at the University of Missouri. He accepted a position with the Geologic Division of the U.S. Geological Survey in 1948 and was assigned to assist in geologic mapping of Pleistocene deposits of eastern South Dakota. In 1949 he was assigned to Fort Morgan, Colorado, with the Water Resources Division, Ground Water Branch, where he conducted the geologic phase of the hydrologic study of the South Platte River Basin. Following this, he was assigned successively to the Atomic Energy Proving Grounds in Nevada, Denver, Colorado, Scottsville, Kentucky, Louisville, Kentucky, and Washington, D.C. before being transferred to St. Paul in 1960 as district geologist. He is responsible for the direction of cooperative groundwater studies of the U. S. Geological Survey in Minnesota.

Our next question then is, "What type of research is needed?" Perhaps first and foremost and unrelated to the common concept of need for research, is the need for social and economic research in the field of water supply to evaluate the relative needs of various types of consumers and to evaluate the laws which should be formulated in order to most efficiently utilize the available water supplies. Granting that this research must be done, the technical person in the field of hydrology must make available to planners a clear picture of the occurrence, availability, and quality of water in the state; a task which we cannot now fulfill.

In order to describe the technical research needed to evaluate groundwater supplies, I will consider three main categories of groundwater evaluation. First, the yield that may be obtained on a more or less sustained basis from an aquifer or aquifer system. Second, the quality of water which can be obtained; and third, management practices which should be considered for overall management of the water supplies of the state. Under the first category of yield, consider areas from which we can obtain relatively large yields for municipal, industrial, or irrigation uses. In many states, information on aquifer yields is well known, and mapping of aquifers has progressed far enough so that an accurate yield figure is available for principle aquifers. But in Minnesota, most of our aquifers are not mapped and only a few aquifers have been studied sufficiently to determine yields. When the U.S. Geological Survey first started our current watershed studies in cooperation with the Minnesota Division of Waters, the best state groundwater coverage was that obtained by the Minnesota Geological Survey and described in their three publications on the groundwater in southern, northeastern, and northwestern Minnesota. These consider county by county, the groundwater availability in the state. The information included was based generally on a cursory knowledge of the geology of the counties plus information from an average of 15 wells per county. At the present time, under our watershed program, we have increased this so that in those parts of the state that have been studied, we have some 300 records of wells per county. In addition, we have augered about 25 holes per county to map the shallow glacial drift aquifers. Where the watershed studies have not been completed, we cannot predict, within a very wide range, what yields will be obtained from a well in the glacial drift in any given area. Where the studies are complete, we can make reasonable estimates of potential yield of the major aquifers. But we still are not able to give detailed information on aquifer yields nor on how the potential yield of an aquifer can best be realized. This is information that is needed for economic location of wells in much of the state. The glacial drift is complex. Sand lenses pinch out, large variations in permeability occur vertically, clay layers are unexpectedly extensive. A first need for research in the state then, is to map the major aquifers, particularly in the glacial drift. The mapping is needed over a major part of the state in order to adequately locate sites for large yield wells for municipal and industrial use.

The quality of groundwater available throughout the state ranges from water with almost no dissolved solids to water which contains three to four times the dissolved solids of sea water. In general, the groundwater is of satisfactory quality for most domestic purposes and quality is not a limiting factor for groundwater use. Nevertheless, we need more precise mapping of water quality in order to evaluate alternative solutions to water problems. For example, in the Middle River watershed there is an extreme range in dissolved solids from a few hundred parts per million to more than 30,000 parts per million. The water occurs in productive aquifers lying in an east-west line across the watershed. Determinations of not only the exact details of such a variation in quality, but also the reasons for such a change in quality are needed.

For years we have been sampling water and determining only the major ions. We need to know the concentration of trace elements as well. Research is needed not only to acquire this information, but also to determine what dissolved constituents in water are significant and why. We need longterm monitoring of a network of observation wells for quality and we need several times the density of quality sampling stations that can be undertaken under present programs. Particularly in areas of heavy pumpage, changes in water quality of great significance may be occurring.

The last category, management, is the most complex. The groundwater reservoir in Minnesota is many times larger than any surface-water reservoir that could be constructed in the state and it must be fully utilized if the state is to have high quality water available at a reasonable price in the immediate future. We must think of this reservoir of groundwater much as we would think of a reservoir of surface water in that it is a resource that must be managed. It is not enough to consider the reservoir only as a source from which water can be pumped during emergencies and attempt to preserve this reservoir from depletion. This would be comparable to filling a surface-water reservoir in the spring and insisting that no one could use it except in major emergencies because it then might be slightly lowered and thus leave less water for other emergencies later on in the year. Although management of groundwater reservoirs is now practiced largely in areas of the west where water shortages have been critical for many years, it is a practice which is not only feasible, but is an economic necessity even in relatively water-rich areas of Minnesota. Removal of water from the groundwater reservoir must be controlled and understood so that the most efficient methods of both adding and removing water from the reservoir may be pursued. In order to manage effectively, we again need research. We need to know not only the yield and quality of water which a given aquifer can produce, but the movement of water within the container and into and out of the container. Within Minnesota, we need to develop hydrologic maps for most of the state on the same scale as the topographic maps. Specifically, we need to construct maps at this scale which show the configuration of the water table, areas of equal transmissibility, areas indicating volume of storage of groundwater, the pattern of flow of groundwater, areas of natural recharge, and areas of natural discharge. Beyond this we need to know the characteristics of the aquifer unit as related to the movement of groundwater within the system.

To produce such maps, we must develop knowledge of the horizontal permeability and thickness or transmissibility of aquifer units at many

points. For example, we need to know the water storage and water transfer characteristics of glacial till sheets. We need to know the transmissibility of the bedrock units in places other than the Twin City area. One of our most pressing needs throughout the state is for a determination of vertical permeability of the so called confining beds above and below artesian units. We have essentially no knowledge of this factor in the Twin City area, and it is critical for making realistic estimates of aquifer yields. In the rest of the state, it is needed for an understanding of water movement.

Closely tied to vertical permeability is a knowledge of areas where recharge takes place. We have little knowledge of the rate of recharge throughout the state or the areas where recharge occurs. We recognize that recharge from lake basins and from streambeds may be of great significance, particularly in the areas where groundwater levels have been lowered through pumpage. But we do not have information on the rate at which water can move through the bottom sediments of the surface-water basins. The sustained yield of the groundwater system is limited by the recharge that takes place to the system. In order to determine the recharge which takes place through the land surface under natural conditions, we must have a knowledge of the infiltration capacity of soils as well as the underlying bedrock units, the characteristics of precipitation, runoff, and evapotranspiration. We should determine recharge potential not only within the undisturbed natural environment, but also in the areas that are intensively cultivated and areas of intensive urban development. In order to make such a determination, a research project on several small watersheds should be undertaken. Such a project would have to determine such complex variables as affects of frost penetration, snowmelt, temperature, rates of precipitation, gradient, soils, plant types, and drainage developments. As an example, the construction of storm sewers, streets, and paved parking lots have a significant effect on the natural recharge to the groundwater body as well as characteristics of surface-water runoff. To determine how much effect such structures have, it is necessary to do intensive research on both an area where such structures exist and on a similar area where no development of significance has yet taken place.

We need to develop information on the rate of travel of groundwater through the aquifer system. This is still a new field of study and one which has been little touched, even in theoretical considerations, yet it has great significance in the analysis of the movement of groundwater contaminants. Possibly one means of getting at a figure for rate of travel is utilization of geochemical data. This might be done by obtaining the chemical constituents in the water at one point and examining the changes which take place along the flow lines from the point of recharge to the point of discharge. By analyses of the known chemical quality at two points, and the changes that take place, it might be possible to predict the total flow rate by knowing the total change in chemical constituents.

When a stress is placed on groundwater system, for example, by pumping large quantities of water out of it artifically, a great number of changes take place within the system. Some of these are understood, most of them are but poorly understood. We need basic research as to what happens when a stress is placed on each of the major groundwater systems in Minnesota. For example, what changes in recharge and discharge relationships can be expected when large quantities of water are removed from glacial drift aquifers? What changes take place in porosity and permeability in the bedrock aquifers when the artesian head is significantly lowered? If we consider artificial recharge as a means of increasing the water supply available from artesian aquifers, is it proper to lower the artesian head in these aquifers before we initiate artificial recharge or should artificial recharge be initiated when the piezometric surface in the aquifer is relatively high? As another example, if we pump fresh water from the relatively thin aquifers in the Red River basin, will it induce upward recharge of saline water and deteriorate the quality of the fresh water that is found in these shallow, near-shore deposits of Glacial Lake Agassiz? By priority then, I would suggest that we need: First to understand the container or aquifer units in which the water is found; Second, we must determine the quality of the water in these units; and Third, determine the dynamic equilibrium of groundwater in the system under natural conditions and conditions of stress. Obviously, this presentation emphasizes primarily applied research in the field of groundwater mapping. Out of this program of applied research, problems will arise which can only be solved by basic research in the occurrence and movement of water and its chemical quality. Research in these fields should go on simultaneously with the applied research program I have suggested. The solutions which come out of such a basic research program will then be solving problems based on real needs.

Prepared Statement by Paul K. Sims

The previous paper clearly sets forth a major area of deficiency in the State of Minnesota--a lack of precise knowledge of our groundwater resource. As a geologist having the responsibility for providing the hydrologist with the geologic information he needs to do his job, I am very much aware of the inadequacy of our knowledge of such simple facts as the distribution, thickness, and lithology of even the major aquifers and aquitards in the state. Without this knowledge the hydrologist cannot possibly obtain the quantitative data that are needed as the basis for the management of our groundwater resources.

As this is a conference on water resources research needs in Minnesota, I would like to give you a few facts about the status of geologic knowledge in Minnesota, emphasizing of course the information needed for water-oriented studies. I shall do this by reference to geologic mapping--a good indicator of broad geologic knowledge. Geologic maps are made at different scales and, of course, are useful for different purposes. I shall first discuss our state geologic map and then proceed to more detailed maps.

Minnesota has state geologic maps of both the bedrock and the surficial (or glacial) materials at a scale of 1:500,000, or about 8 miles to the inch. Both maps were published in 1932. These maps are useful for those problems that require only a general geologic knowledge, such as state-wide planning. However, they are now known to be inaccurate in many places and are out-of-date. By comparison, all but three states in the Nation have more modern state geologic maps.

We are now in the process of revising the bedrock geologic map of the state. The map is being prepared at twice the scale of the older map, on the excellent U.S.G.S. 1:250,000-scale topographic base maps, which cover two degrees of longitude and one degree of latitude. One of the eleven sheets that ultimately will comprise the new state geologic map has been published. This is the St. Paul sheet, which covers all of southeastern Minnesota, or about 7,000 square miles. Mapping is in progress in the New Ulm, Hibbing, and Two Harbor sheets, an additional 18,000 square miles. These maps will greatly expand our geologic knowledge and meet most of the State's current needs. They are not wholly adequate, however, for the needs of the hydrologist. I would like to emphasize also that we have not yet started the remapping of the state's glacial deposits; knowledge of the surficial deposits is urgently needed as background for the hydrologic studies of the state's 39 watershed units.

The third and most detailed type of geologic map is prepared at scales of either 1:24,000 or 1:62,500. These utilize the standard topographic 7 1/2-minute or 15-minute quadrangles as bases. Maps at this scale show basic geologic information adequate for most needs. Points on the ground can be readily located, and the user can read directly from the map the kind of rock that underlies any point.

As most of you know, it is only in the last decade that standard topographic maps have been available for any substantial part of the state, and even today only about 50 per cent of the state is covered by these maps. Not surprisingly, therefore, geologic maps at the scale of the standard topographic maps are few and far between in the state. Published geologic maps at scales of either the 7 1/2-minute or 15-minute quadrangles cover less than two per cent of the state. They include maps of part of the Twin Cities metropolitan area, Duluth, and a few additional areas in central and northeastern Minnesota. By comparison, it is interesting to note that 17 per cent of the United States is covered by detailed geologic maps of 7 1/2-minute or 15-minute quadrangles. We lag badly in this respect.

In summary, much remains to be done geologically in the state before our groundwater resources can be evaluated adequately. Geologic maps are

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only one of the kinds of geologic data needed. Our present qualitative data must be qualified and, lest we be too late with too little, these studies should begin now.

Prepared Statement by Gene H. Hollenstein

How important and necessary is a program of research on water supply? I would like you to consider a statement by Raymond L. Nace, U.S. Geological Survey, presented at the International Water Quality Symposium held in Montreal, Canada, on August 25, 1966. "Much current discussion about conservation seems to take for granted a debt to posterity -- an obligation to bequeath to the next generation the same or better quality and the same quantity that we have now. However, world population, water demand, and exploitation of resources are growing at exponential rates. Meantime the supply of fresh water is not growing at all. It is shrinking. It seems to be almost a foregone conclusion the water legacy of the United States to Century - 21 will be tarnished." In the light of such observations from an eminent water authority such as Dr. Nace, it is obvious that an expanded program of research and water-supply investigations is a matter of utmost urgency and necessity.

One aspect of research in water supply involves the determinations of the hydrologic and related natural resources environment of the state before their exploitation by man. We must reconstruct precipitation and temperature records, surface and groundwater conditions and levels, type and extent of vegetative cover, and other related hydrologic conditions so that we can evaluate the changes that man has made. We can then undertake specific research to find solutions to the quantitative and qualitative water problems that the works of man have wrought in Minnesota during the past 100 years.

Research is needed to determine the effects of urbanization in metropolitan areas on groundwater levels and streamflow. It is needed in the iron range areas and in sand and gravel mining areas to determine the effects of mining activities on hydrologic conditions. We need to find out what chemical changes in ground and surface waters have occurred as a result of industrial, domestic and agricultural waste disposal.

We must study all aspects of water supply but especially the interrelationship between climatic factors and surface and subsurface conditions which control water movement at and beneath the land surface, such as the research done by Peter Meyboom, Groundwater Geologist with the Water

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GENE H. HOLLENSTEIN graduated with a B.S. in Geology from the University of Wisconsin in 1956. He completed one year of post-graduate study at the University of Wisconsin in 1956-57. From 1958-1965 he was employed as a geologist by the Division of Waters, Minn. Conservation Department and in 1965 he was promoted to Ground Water Hydrologist with the Division of Waters. He is secretary-treasurer of the Twin City Geologists.

Research Branch of the Canadian Department of Energy, Mines and Resources. Meyboom's work involves a study of local and regional groundwater flow patterns in the Saskatchewan prairies, and indicates that areas of apparently simple groundwater flow patterns of either discharge or recharge are actually areas of complex hydrology and that several different situations of flow occur due to vegetative cover, topography and climate. Research of this nature in certain lake areas of Minnesota might help solve some of the water-supply problems relating to lake levels.

This phase of research might also include the following studies, all of which were proposed by the Task Group of the Consulting Council of the Water Resources Research Center: Seasonal climatic effects of temperature and precipitation on ground and surface water availability in Minnesota; Precipitation patterns and frequency analysis; The relation of these patterns to water supply and their effect in modifying the hydrologic environment; Water - soil - vegetation relationships and effect on total water supplies; Changes in hydrologic properties with time under applied stress and the effect on water supply; and Surface water geology - groundwater interrelationship and influence of the various factors on water movement behavior and yield.

Important and necessary is research on research methods. New techniques and tools are needed for use in making better quantitative and qualitative determinations of the availability and distribution of our water resources. Development of new methods of groundwater exploration would help reduce the present high cost of test drilling now required to determine available groundwater supplies in areas where little prior information is available.

The space research program has led to development of remote sensing techniques which are applicable to hydrologic studies and which are presently being included in a plan by the U.S. Geological Survey as part of an advanced hydrologic and geologic remote sensing program using unmanned satellites. The remote sensing program will employ research in aerial photography, infra red temperature studies, radar imagery and many other new techniques.

Research in new computer programs relating to data assemblage, assimilation and interpretation will provide rapid data retrieval and reduce the number of man hours required to perform many presently tedious tasks necessary for compilation and evaluation of hydrologic information.

New instrumentation techniques, such as an instrument which could be used to measure the vertical permeability of the various geologic formations in the field, would be helpful in evaluating the water supplies in Minnesota. If we could develop a device to measure streamflow accurately without installing permanent stream-gaging stations, a large saving of funds would result. We also need to develop new equipment which will give accurate and complete chemical quality analyses in the field to eliminate costly and time consuming laboratory procedures.

Research studies of hydrologic and related conditions in specific areas of the state may enable us to develop previously unknown or neglected sources of water or solve particular problems of pollution, uneven distribution, variability of supply and demand, and natural quality. It parts of northwestern Minnesota, for example, the only presently available water supply for private domestic supply is from individual wells containing water with high salt content. Investigations are needed to determine economical means of providing low cost treatment of this groundwater to give a potable and more desirable water supply for home use. Another subject for research might be the effects of land drainage in specific agricultural areas of the state and the development of new methods for utilizing these lands.

Another phase of needed research involves a study of present water use practices in order to develop improved technology for water use for various purposes. Many of the present industrial processes in use in the Twin Cities Metropolitan area waste large amounts of water and better methods of conservative use of our water supplies are needed. In some suburban areas of the Twin Cities the soils and underlying glacial deposits are very sandy and constant watering is needed to maintain desirable green lawns because of poor soil water-holding capacities. The amount of water needed for this purpose during the hot summer months of many years often creates community water shortage problems and results in sprinkling bans or restrictions. A solution to this problem may be the development of new drought resistant strains of lawn grasses and new methods of treating the soils to increase the water-holding capacities. Through research, these problems can be solved.

A study of the legal aspects of water supply is needed to develop new legislation and provide new methods of controlling water appropriations to insure dependability of water supplies both qualitatively and quantitatively for future generations. These are only a few of the many areas of research in water supply that are needed so that we in Minnesota may learn how to adapt to our constantly changing environment and maintain adequate supplies of good quality water for the years ahead.

Prepared Statement by Douglas W. Barr

The field of water supply is a big one. Richmond Brown has limited his discussion to the area of groundwater supply. In fact, the major portion of his discussion related to the taking of inventory of the groundwater supplies of Minnesota. Generally speaking, this would not fit my definition of research, but what we call it is unimportant. The inventory taking is necessary work. There should be an ongoing program of this type of inventory taking in Minnesota. Minnesota has had such a program but I believe it should be proceeding at a faster pace than it has been. Richmond Brown has discussed many of the elements involved in the inventory of groundwater resources in Minnesota. He has presented a good picture of the type of work which lies ahead.

At the present time, what is needed in most of Minnesota still is a macro scale study of groundwater geology. Richmond Brown mentioned the three publications prepared by the University of Minnesota, which have been available for many years. These publications have been extremely valuable. The generalized picture of the groundwater situation outlined in these publications represents a tremendous forward step--from an almost complete lack of information to a general knowledge of the aquifers and their water quality. The next step in the inventory process will require much more work, and the increment of value will be less than the previous work. Nevertheless, it is a necessary process. In the Twin Cities area, a much more intensive study of the aquifers was prepared many years ago by Dr. George Schwartz. Similar studies are only now being made in other parts of the state. Very recently, the picture in the Twin City Area has been greatly refined by work under the direction of Paul Sims, but this covers even less area than the work of Dr. Schwartz. The point is that the macro scale, generalized picture comes relatively easily. It is of immense value, and is the first step of the inventory process. The refinements come later and necessarily are confined to a smaller area and require even greater amounts of work.

In Minnesota, there are few places where there is a critical need for the intensive groundwater inventory. This is not to say that this inventory should not be proceeding. There is no crisis, however, and the inventory should proceed at a deliberate pace. In regard to the inventory of water resources, we should not fail to mention the need for further inventory on surface water supplies. Perhaps we are in somewhat better shape in the surface water inventory than we are in the groundwater inventory. While it is true that the available stream gaging records seldom apply directly to individual water-supply projects, we should not expect this kind of record. Rather, the records should be the basis for deriving an understanding of the physical principles which govern water supply and the means of testing theories.

It is the nature of research to cause a concentration of attention on narrow areas. There is a tendency to lose the broad picture. This become particularly important in the area of the regulation of water resources.

DOUGLAS W. BARR graduated with a B.S. in Meteorology from the University of Chicago and served in the U.S. Army Corps from 1944 to 1946 as a weather forecaster in western United States, the Pacific and the Far East. After the war, he returned to the University of Minnesota and received a B.S. degree in Civil Engineering in 1949. From 1949 through 1952 he was a Civil Engineer with the Minn. Division of Waters, serving as drainage engineer and hydraulic engineer. From 1952 to 1953 he served with a consulting engineering firm in Iowa, doing primarily drainage engineering and municipal engineering. In 1953 he joined Adolph F. Meyer, Consulting Hydraulic Engineer, in Minneapolis, and is still a member of that firm. The firm now bears the name Barr Engineering Co. He is a fellow the American Society of Civil Engineers and has just completed a term as president of the Northwestern Section. He is a Professional Member of the National Society of Professional Engineers and is a past president of the Minneapolis Chapter. He is a member of the Consulting Engineers Council and is serving on a national committee on Water Resources. He is also a member of the American Meteorological Society, the American Geophysical Union, and the National Water Well Association.

When man manipulates one element of his environment, there is bound to be a reaction in the other elements of the environment. In the past, we have proceeded with the manipulation of one element of our environment without even a second thought to possible side effects. In fact, we tend to be blind to the side effects until they reach crisis proportions. As an example of this, we can point to the use of surface waters, and to a lesser extent the groundwaters, as a vehicle for disposing of the wastes of civilization. Not until the stench is all about us, do we awaken to the undesirable side effects of our use of water as the transporting vehicle for our wastes.

Another example of insufficient foresight in regard to side effects may be the matter of the relationship between groundwater and surface water. Since Minnesota is in a semi-humid climate, the matter is particularly critical. To a large extent, the lakes and streams, of which we are so proud, are a surface expression of the groundwater. We should know more about the extent to which these surface lakes and streams would be affected by lowering of the groundwater table before extensive pumping is undertaken. It seems unlikely that we would condone widespread and intensive development of our Minnesota aquifers until there has been considerable research into the effect which such development would have on the surface lakes and streams.

I cannot agree with Richmond Brown that the groundwater aquifers should be treated as a huge reservoir from which water can be taken without regard to its replenishment. We have seen the folly of this practice in the western states where water has been treated as a resource to be mined. In those western states, many of the aquifers are nearly dry, and still more wells are being installed. The tragedy is that these wells have supplied water principally for irrigation, or perhaps I should say for evaporation, because far more water is lost through evaporation than is consumed by the crops. The value received to those states for the mining of this irreplaceable water has been very small.

Richmond Brown has compared the groundwater resource to a surface water reservoir. If he carefully applies that comparison, he will note that the surface water reservoir is depleted only to the extent that it will be replenished in the spring, or in the foreseeable future. Any other use of a surface reservoir would be impractical and unthinkable. Likewise, the groundwater reservoir should be utilized only to the extent that they will be replenished in the foreseeable future, partly because this reduces the effect of the groundwater pumping on the surface lakes and streams, and partly because the greatest value of the Minnesota groundwater aquifers is not as reservoirs but rather as conduits through which water is distributed. It is our good fortune in this metropolitan area to be able to sink a well a few hundred feet into the ground to contact the Jordon aquifer and therby have the water supplied to within a few feet of the point of water use.

I can certainly agree with Richmond Brown that the principal need for research in water supply is in the social and economic area. We must establish our scale values better than we have in the past. We must recognize the characteristics of water which makes it valuable to various groups within our civilization. A water supply is not merely a "water supply."

It is a supply of cold water, or is a potable water supply, or it is a water containing nutrients or gases which are vital to living organisms, or it is a cheap liquid for supporting and transporting other materials. Even when water is used simply as H_2O, it must come with the proper characteristics to be useable. Therefore, I believe the greatest need for research in water supply is in establishing the value of water in its various forms, various qualities, various locations, and various quantities.

We must not again permit ourselves to be launched upon never ending programs which will waste our water toward short sighted goals. We should be able to use our water today to serve our present needs and still pass this resource on to our children for whatever needs it may serve in the unforeseeable future.

RESEARCH ON WATER POLLUTION

Principal Paper by Lyle H. Smith

"The policy of the state," as set forth at MS 115, "is to provide for the prevention, control and abatement of pollution of all waters of the state, so far as feasible and practical in furtherance of conservation of such waters and protection of the public health, and in furtherance of the development of the economic welfare of the state." The purpose of Laws of 1963, Chapter 874, is declared to be "to safeguard the waters of the state from pollution by (a) preventing any new pollution and (b) abating pollution existing when Laws of 1963, Chapter 874, became effective, under a program consistent with the declaration of policy above stated."

The Federal Water Quality Act of 1965, PL 89-234, states: "The purpose of this Act is to enhance the quality and value of our water resources and to establish a national policy for the prevention, control and abatement of water pollution." It also states that "it is hereby declared to be the policy of Congress to recognize, preserve and protect the primary responsibilities and rights of the states in preventing and controlling water pollution, to support and aid technical research relating to the prevention and control of water pollution, and to provide Federal technical services and financial aid to state and interstate agencies, and to municipalities, in connection with the prevention and control of water pollution."

The Minnesota Water Pollution Control Commission, since its inception in 1945, has been working to carry out these policies and achieve the necessary goals, and marked progress has been made. The Commission and staff are continually aware that the problems of water pollution control are growing more complex with a greater population, more and greater concentrations of population, increased and diversified industry and other factors along with a greater demand for more and cleaner water because of the previously mentioned factors, as well as the great increase in water-oriented recreation with individuals having more leisure time, the ability to travel greater distances, higher income, etc. In order to keep pace with the problems a number of things are needed, one of the paramount

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LYLE H. SMITH graduated from the University of North Dakota in 1938 with a B.S. in Civil Engineering and from the University of Minnesota in 1943 with a M.S. in Civil Engineering. Before being employed with the Minn. Dept. of Health in 1941 he was employed by the North Dakota Highway Dept. and the Soo Line Railway. He served in the Sanitary Corps during World War II reaching the rank of Major. Almost all of his career with the Dept. of Health has been spent in water pollution control. He became Chief of the Section of Water Pollution Control in 1961 and at the same time became Executive Engineer of the Water Pollution Control Commission. He is a registered professional engineer in Minnesota, a diplomate of the American Academy of Environmental Engineers, past president of the Central States Water Pollution Control Association, past director of the Water Pollution Control Federation and is a member of other professional societies.

being research. This has been recognized by the provision in numerous federal acts for support of research of various kinds, including that related to water pollution control. State water pollution control agencies take advantage of the various research projects supported by the Federal agencies and believe that this is a legitimate activity for such agencies.

The Minnesota Department of Health in years past, specifically 1956 through 1960, sponsored certain research on Lake Superior for the Water Pollution Control Commission. This work, done by the School of Public Health of the University of Minnesota, resulted in a series of reports on the limnology of Lake Superior. Studies were made of temperatures, water movement and nutrients. The Department of Health, in 1964, received a demonstration grant from the Department of Health, Education and Welfare to study the "Channel Aeration Process" in sewage treatment. This study, now in progress, is of the new sewage treatment facilities at Glenwood, Minnesota. Research of a very limited nature is carried out by the staff of the Commission as time, funds and personnel permit. This has included evaluation of treatment methods, toxicity studies, etc.

As stated earlier, the need for research has always been recognized. Areas of greatest need for such research, the results of which could most effectively be used, are the study of the following:

Various treatment methods and processes to evaluate efficiency, effectiveness, practicability and economy;

Methods for removal of nutrients from sewage by chemical and biological means;

Removal of nutrients from lakes and ponds by various means, including harvesting of weeds, algae and other aquatic life;

Bacteria and viruses as to survival in various methods of sewage treatment, and the probabilities of disease transmission from effluents and stabilization ponds;

Effect of pesticides, herbicides, etc., on water quality and bottom fauna;

Effects of "trace" elements and combinations of such elements on treatment processes and their long range effects on humans and also biological activity in receiving waters;

Groundwater recharge and the quality of water necessary for such recharge;

Effect of private sewage disposal systems along lake shores on water quality;

Development of classification and adoption of standards of water quality and purity;

Coordination and cooperation of water resources related agencies;

The fate of various pollutional constituents in passage through various types of soils;

Control, reduction and reuse of wastes;

Methodology of water quality monitoring;

New and improved methods of sewage and waste treatment; and

Low flow augmentation and effects on water pollution control problems.

Many more studies of somewhat more limited application and benefit could be enumerated, such as fish rearing in stabilization ponds, significance of slimes, significance of bacterial concentrations in certain industrial wastes and surface waters, relationship and epidemiological significance between bacterial quality of waters and the number of bathers at a natural bathing beach, etc.

Prepared Statement by Albert C. Printz, Jr.

I am sure that when Lyle Smith pointed out that research is of paramount importance he meant this in the context that its need is not just to keep pace with the problems, but more positively--to get ahead of our problems. It is in this latter framework that research is a very important weapon in the overall attack against pollution. The analytical tools, scientific knowledge, and engineering controls which served well for the problems of the past are proving increasingly inadequate to cope with the foreseeable future problems. Thus, water pollution research must develop effective new technology while program administrators attempt to hold the pollution line with the already available knowledge.

The need for more research has virtually the unanimous concurrance of all persons concerned with water pollution control. In listing research needs in Minnesota, Lyle Smith has reached the same conclusion as most others, ie, invariably the highest priority of research is the need to develop new and improved techniques for waste treatment and specifically to develop technology to permit more waste water reuse. For purposes of elaboration on this point, I invite you to review four significant publications: "A 10-Year Program of Federal Water Resources Research" prepared by the Federal Council for Science and Technology, Committee on Water Resources Research, February 1966; "Water Management and Control," National Academy of Sciences, National Research Council, 1966; "Restoring the Quality of our Environment," report of the Environmental Pollution Panel, President's Science Advisory Committee, November 1965; and "A Special Report on Water Supply and Pollution Control - Are We Ready For The Future?," Water Works and Waste Engineering, Volume 2, 1965.

In the past, research was directed at defining the problem. From this, a new course has been charted; one towards the major goal of developing the necessary control methods for a total water reuse program. Our nation has already entered into a limited water reuse phase; however, continual reuse of water will not be a reality until we can practice the total pollution control of municipal and industrial wastes, urban runoff, rural runoff resulting from man's activities, and natural sources. Only at this time will there no longer be water shortages except in those locations having large consumptive use.

A considerable amount of progress has already been made under our present program, especially when you consider that the total Federal expenditure for research to develop new treatment technology through Fiscal Year 1966 has been less than $5 million. Under this funding, it has been shown possible at laboratories and pilot scale, to achieve any degree of waste treatment desired. It is safe to say that as a result of this past research, many of the water pollution problems facing our nation today can be resolved by the application of existing technology. In fact, over the next few years, the most significant strides in water pollution control, on a national basis, will be made in this way.

The concern of the public and Congress dictates the need for a greatly accelerated program of research incorporating the best talents of the Federal Government, the States, the university and private research communities, and industry through the mechanisms of in-house research, contract research, and field evaluations of the most promising treatment processes, to determine efficiency, cost, and design criteria leading to full scale applications.

In order to carry out this mandate, Congress has not only provided for Federally operated and staffed regional laboratories, but also for the other elements of the program by means of the recently signed amendments

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ALBERT C. PRINTZ, JR. received his B.S. in Civil Engineering from the University of Florida in 1959 and continued on to receive his Masters Degree in 1960 with major emphasis on sanitary and municipal engineering. From 1960 to 1961 he served as a Research Assistant in the Department of Civil Engineering, conducting contract research for the Office of Civil Defense and Mobilization. During the period of 1961 to 1962 he served as a Staff Engineer in the Region V office of the U. S. Public Health Service, participating in reimbursable work for the U. S. Army Corps of Engineers. Between 1962 and 1963 he helped organize and conduct the Detroit River-Lake Erie Project, the Public Health Service's first resident study in a major metropolitan area under the enforcement provisions of Public Law 660. Capacities in which he served were: Asst. to the Director and Chief of the Inventory and Reports Section. In 1963 he was transferred to Minneapolis as Resident Project Director to establish a resident study of 270 miles of interstate waters in Minnesota and Wisconsin. During this assignment he has served as the Public Health Services's representative to many organizations. Early in 1966 he resigned his active duty commission with the Public Health Service in order to join the Dept. of the Interior and continue in the field of water pollution control with the Federal Water Pollution Control Administration. In mid-1966 he was appointed to the newly created position of Regional Water Quality Standards Coordinator for the Great Lakes and Upper Mississippi River Basins. It is in this capacity which he serves at the present time.

to the Federal Water Pollution Control Act. These amendments -- The Clean Waters Restoration Act of 1966 -- provide the funding necessary for an accelerated program. As finally adopted, Section 201 (a) of the Clear Waters Restoration Act of 1966 amends section 6 of the Federal Water Pollution Control Act to authorize the Secretary of the Interior to make grants in two basic areas with certain limitations:

A. Grants to any State, municipality or intermunicipal or interstate agency for

(1) Assisting in the development of any project which will demonstrate a new or improved method of controlling the discharge into any waters of stormwater overflows. Authorized for Fiscal Year 1966, 1967, 1968, and 1969 is $20 million per year to carry out this work. Limitations include: project approval by the appropriate State agency and the Secretary, maximum of 75 per cent of the estimated reasonable cost of the project, and the project must serve as a useful demonstration of the purposes of the Act.

(2) Assisting in the development of any project which will demonstrate advanced waste treatment and water purification methods or new or improved methods of joint treatment systems for municipal and industrial wastes. Authorized for this research was $20 million per year for each of the Fiscal Years 1967, 1968, and 1969. The same limitations apply here as with the stormwater overflow grants.

B. Grants to persons for research and demonstration projects for prevention of pollution of waters by industry including, but not limited to treatment of industrial wastes. Authorized were funds in the amount of $20 million per year for each of the Fiscal Years 1967, 1968, and 1969. Limitations are concerned with a maximum grant per project of $1 million, no grant for more than 70 per cent of the cost, and the method developed or demonstrated shall have industry-wide application.

Congress has set the stage, and much still remains to be done. We are essentially just getting underway with a massive multiple attack on the pollution problems of the nation.

The list of research needs spelled out by Lyle Smith is lengthy but also inclusive. Although through the riddle of semantics, Lyle Smith may have already included all necessary research, I should like to add to the list a few areas of shortcomings in our current technology.

Complete disinfection of waste effluents;

Ultimate disposal of waste concentrates in a nonpollutional fashion;

Control of pollution from irrigation returnflows;

Abatement of pollution from watercraft; and

Assessment and evaluation of socioeconomic factors in water pollution control.

The extensiveness of the lists tend to bring home a statement of the President's Science Advisory Board: "We now know that the full effects of environmental changes produced by pollution cannot be foreseen before judgements must be made. The responsible judgement therefore must be the conservative one." I sincerely hope that this view will be examined, adopted, and supported by all Minnesotans who are blessed with such a bontiful supply of water.

Prepared Statement by Hibbert Hill

It might occur to a reader of the comprehensive list of needs in the preceeding paper to wonder what sanitary engineers and biologists have been doing all this time that the range of unkowns is still so great. After all, we have been at the business of sewage disposal and public water supply in a modern sense for some 75 years, and a great deal of money has been spend on research in these fields. It is worth a few minutes of our time to recall how we got into the position in which we find ourselves.

I remember that during my childhood, which doesn't seem long ago to me, typhoid fever was a common disease, people I knew died of it, and others I knew nearly did so. I was aware of infectious disease for another reason, too. My father had graduated in the first class from Johns Hopkins brand new school of public health. It was evident to him by the time I knew him that the infectious disease, which had scourged mankind for centuries could be wiped out. In fact this was accomplished during his life-

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HIBBERT HILL is a resident of Carver County, retired Vice President, Engineering, Northern States Power Co., and presently Research Associate, Dept. of Botany, University of Minnesota. He is a graduate of the University of Minnesota, Civil Engineering, 1923. He was a Junior Engineer, U.S. Coast and Geodetic Survey, 1923-24; Instructor in Civil Engineering, University of Minnesota, 1924-28; and Associate and Senior Engineer, U. S. Engineer Office, St. Paul, 1928-36, engaged principally on the design and construction of a 9-foot channel in the Mississippi. He was with Northern States Power Co., 1936-1966, first as Superintendent of St. Anthony Falls Water Power Co., later Hydraulic Engineer, Chief Engineer and Vice President. He was a Lt. Col., Corps of Engineers, 1942-45, Deputy Chief Engineering Division, Office Chief of Engineers, engaged largely on the design of military construction; and was awarded the Legion of Merit. Since 1945 and continuing, he has been consultant to the Corps of Engineers on the construction of various dams in Arkansas, Kansas, and on the Missouri and Columbia Rivers; to the Governor of the Panama Canal on various aspects of the Panama Canal; to the Turkish Government on three dams constructed in Turkey; to Pakistan on Tarbela Dam, Indus River. He was President, Northwestern Section American Society of Civil Engineers, 1936-37; President Minnesota Society of Professional Engineers, 1939; President of Minn. Alumni Assoc., 1955-56; Member of Governor's Advisory Committee on Atomic Development Problems, 1957-58; and Member of Governor's Committee on Air Resources, 1965-66; Member Minn. State Board of Health, 1961 and continuing.

time for most of the infectious diseases, and the excitement of the work he was doing made him want to talk about it. I heard a great deal about typhoid and smallpox at that time.

Inadequately treated water supplies, or supplies taken direct from the nearest source without treatment, were a major source of the disease prevalent at the beginning of this century. The situation was compounded by the discharge of raw sewage into the same sources. In view of the attention given to these matters now, it is difficult to recall that a major city such as Baltimore had no sewer system as late, as I recall, as 1908. Sewage ran in open gutters through the streets. I can remember lines of people waiting at public wells in Minneapolis to obtain their drinking water. Minneapolis had a public supply, but it was raw river water, and suspect on the basis of bitter experience. Thus, it is only a short time, some 50 years, since the relation of water supply and sewage disposal to disease has been generally appreciated. All during this period the overriding, and almost the sole, consideration in the design and construction of water supplies and sewage works has been public health.

In the meantime population and wealth have grown so rapidly that we have not had time, until recently, to appreciate the implications. Wealth and the leisure to enjoy it have resulted in intensified demands upon our lakes and rivers, as sites for homes and cottages, and for all the forms of recreation that water makes possible. Observing Minnetonka now on a Sunday afternoon, I find it almost impossible to believe that in my childhood the appearance of a single power boat in Crystal Bay was occasion for excited interest and comment.

These intensified uses of our waters have quite suddenly brought into prominence effects of pollution which are in addition to the primary concern for public health - algal growths, turbidity, and changing fish populations. They have also brought into prominence polluting factors which only a short time ago, when population was smaller, were of little concern - algal nutrients in sewage effluents, septic tank effluents reaching the lakes through the groundwater, drainage of lawns and gardens, and bottom deposits stirred up by high powered motorboats.

We have not heretofore designed sewage plants with a view to preventing algal growths in the receiving waters, nor lawns to prevent the flow of fertilizers to the lake, nor are we able to speak with certainty of the effects of septic tanks and motorboats. Neither have we been completely oblivious to these needs. Research has been done and some steps have been taken. We know enough to know that we do not know enough to undertake now the apparent great costs of control with confidence that the money will be well spent. Further research is needed to give us that confidence.

However, events are pressing. Planning and construction must proceed even though research yet to be done would improve present abilities. In view of the magnitude of prospective expenditures for water pollution control it seems to me important that there be an agency of the state well equipped with staff and facilities to guide planning and to enforce adequate planning, to be aware of the state of research and to introduce the results

of research, to assist research where assistance would speed answers, and to perform research when need arises. These are in fact functions of the Minnesota Water Pollution Control Commission, but, through no fault of its own, its present staff and facilities are grossly inadequate for the task.

I suggest that research of high priority is required to determine what staff and financing the Commission out to have, and to inform the public and the legislature of the need.

Prepared Statement by Michael A. Barton

The Superior National Forest is not involved in research per se. That is the responsibility of our colleagues at the North Central Forest Experiment Station in St. Paul. However, we do conduct administrative studies to provide answers to management questions. One of the Management questions which we are trying to answer is: "What is the impact of visitors to the Forest upon the quality of the water resource?" Another question is: "What can we do to retard the eventual deterioration of the waters of northeastern Minnesota?" A part of our water resource management activities is devoted to an administrative study to answer these two questions. The Program is entitled the Water Quality Monitoring System of the Superior National Forest.

The primary emphasis of water quality is that of nutrient enrichment, although we do monitor our wells and swimming beaches bacteriologically. The primary sources of nutrient enrichment are external sources such as sewage disposal facilities from urban areas, septic tank effluents from the many homes and cottages surrounding the lakes of the area, and from visitors to the area, such as canoeists, boaters, and campers. The contribution from visitors to the area is a result of the provision of inadequate waste disposal facilities and the failure of the visitor to use adequate facilities when provided.

In order to preserve the present high quality water, the Forest Service is implementing the Water Quality Monitoring System. This system will consist of two phases operating simultaneously. One phase will attempt to develop an index of the enrichment of a lake through indicators of biological productivity. The second phase will directly measure the nutrient status of the water and relate it ot the biological productivity of the water.

MICHAEL A BARTON graduated from the University of Michigan with distinction in 1961. He attended the University of Illinois and the University of Minnesota. He served as an officer in the United States Army until 1963. In 1964 he received the Master of Forestry degree and has completed the majority of his course work for the degree of Doctor of Philosophy. He is currently employed as the Watershed Scientist for the Superior National Forest.

Phase I -- A number of steps are required to establish a suitable index of biological productivity. The first step will be to stratify the lakes on the basis of a number of physical characteristics such as origin, area, volume, shoreline development, maximum and mean depth, length, width, basin profile, and orientation. Three or four different strata will probably be apparent.

Once the strata are established, four lakes will be selected in each stratification in various stages of eutrophication as indicated by gross indicators of productivity. This selection will have to be subjective and must be done with extreme care. Improper selection of these lakes could automatically exclude the determination of a satisfactory index.

The next step will be to relate the various respiration, decomposit on, and waste products of the biota to the level of eutrophication in the lakes. Examples of such products are dissolved oxygen, dissolved carbon dioxide, ammonia, and methane concentrations. In addition, the biota of the lakes will be sampled. Samples will be taken at various times throughout the year and at various horizontal and vertical positions throughout the lake.

Concurrently, certain supplementary information will be obtained to aid in the interpretation of data gathered in the previous step. Temperature, acidity, alkalinity, and certain chemicals necessary for life processes are typical of this information.

The third step is the establishment of a scale using the indicators that were found to be significant. Different indices may be necessary for different strata. After a satisfactory index is established, approximately 50 lakes will be selected for sampling. These lakes will be selected on the basis of use and downstream location from artificial enrichment sources.

Phase II -- The first step of the second phase will be to select the ten most critical lakes for sampling. Each subsequent year the number of lakes will be expanded by ten.

In the initial stages of this phase, the lakes will be characterized biologically. At the same time, a number of chemical determinations will be made. Periodic sampling throughout the year will be necessary until enough background data is obtained to yield an estimate of the natural variation of nutrient concentrations. After such an estimate is determined, chemical sampling will be necessary only on a biannual or triannual basis. Biological sampling, after initial characterization, will be accomplished only when dictated by a change in chemical properties.

Streamflow data will be necessary. Gages will be established where necessary. Eventually as many as fifty streams on the Forest will be gaged.

In the fifth year of system operation, the decision will be made to drop one phase of the system. If Phase I indices can be established, then Phase II will be eliminated in favor of the low cost, simple approach of Phase I. However, if Phase I relationships cannot be established, Phase II

will be expanded to encompass all necessary sampling points and Phase I will be eliminated.

I have briefly outlined the approach of the Superior National Forest in answering certain questions about water quality. There are many other areas in which research is needed. I would like to re-emphasize four of the areas outlined by Lyle Smith. First, the need for research in advanced waste treatment regarding the removal of nutrients from sewage effluents. Second, the removal of nutrients already present in lakes. Third, research in the methodology of water quality monitoring. Fourth, the effect of private sewage disposal systems upon water quality.

Furthermore, there are two other areas, not restricted to the field of water pollution, which are in need of researching. Methods of financing water resources projects are sadly in need of research. The matter of financing all projects (not just research projects) is one of the biggest stumbling blocks in the field of water resources today. Research into various methods of financing and their suitability to the field and surveys of measures used in other areas would be a valuable tool in selling programs.

Secondly, research into the application of the findings of investigators in the fields of education, psychology, and public relations to the problems of proper water resource management. The adequate education of the American public in the field of water resources must be accomplished before we in the field can hope to achieve a great period of growth.

RESEARCH ON FLOODS

Principal Paper by Robert M. Cowan

One of the greatest needs for research in connection with floods has to do with the effect of channel improvements and drainage on flood flows. After every significant flood it seems that statements are made that the flooding was caused or greatly increased by channel improvements and drainage. In 1950 for instance a newspaper carried a story to the effect that there would have been no flooding on the Red Lake River at Crookston and vicinity except for the Corps of Engineers channel improvement then under construction downstream from Red Lakes. The peak discharge at Crookston that year was 27,400 cfs on 7 May. At High Landing, downstream from our project, the corresponding flow was about 3,300, of which some 1,200 was outflow from Red Lakes. Thus the inflow from the intervening local area contributing to the peak was about 2,100 cfs of the Crookston peak flow of 27,400. Our channel improvement was within this local area and probably didn't increase the local contribution by more than 200 cfs. Yet the statement was made that there would have been no flooding except for our channel improvement. Similarly, opinions were expressed that the flooding on the Minnesota River in 1951 and 1952 was due largely to the existing farm drainage projects. Again the increase was probably insignificant compared with the total flow of some 66,600 cfs at Mankato. I don't recall any specific statements of a similar nature after the 1965 and 1966 floods but very likely some were made and very likely more will be made in the future.

Our position on the matter of both channel improvement and farm drainage is that such effect as there is will ordinarily be to increase the peak discharge slightly; however, the amount of the increase is believed very small compared to the opinions generally expressed. In some cases we have allowed as much as 10 percent increase in the design discharge for a channel improvement in a rural reach. Such improvements are usually based on a 10-year flood. In designing these channel improvements, we feel that this 10 percent increase is probably more than the actual effect of the project, but we have allowed this much to provide a factor of safety in the capacity of our waterway. It is also probable that the larger the flood, the less the effect of the channel improvement or drainage project, at least on a percentage basis. Unless there has been some research on this subject in recent years which has escaped the observation of our office the most

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ROBERT M. COWAN received his degree of B. S. in Civil Engineering from the State University of Iowa in February of 1936, having also attended Rochester Junior College, Rochester, Minnesota. Following brief service as Assistant County Highway Engineer in Olmsted County and Assistant City Engineer in Rochester, he accepted an appointment with the Corps of Engineers in September 1936 and initially worked on construction in the St. Paul District. Since December 1937 he has worked on hydraulics, hydrology, and hydroelectric power studies with the Corps of Engineers in the Providence (R.I.) District, the Buffalo (N.Y.) District, the South Atlantic Division Office and the St. Paul District. He has been Chief of the Hydraulics Branch in the St. Paul District Office since October 1948. He is a member of the American Society of Civil Engineers.

authoritative work on this subject was in the 1920's by Professors Woodward and Nagler at the University of Iowa, published in the transactions of the American Society of Civil Engineers in 1929. Professors Woodward and Nagler studied records of stream flow in the state of Iowa, comparing flows from drained areas with those from undrained areas. Their study indicated that drainage did not increase peak flows but they acknowledged that more investigation was needed.

I have talked to Professor Manson of the University of Minnesota several times with regard to the effect of pothole drainage and general farm drainage on peak discharges. I know that it has been his opinion that such drainage reduces flooding by creating in effect a large sponge to absorb the flood runoff rather than increasing the flow in the stream as commonly thought. I would like to see further research with regard to the effect of agricultural drainage and it may be that Professor Manson is including this in his research project on the effect of pothole drainage upon groundwater resources.

It is suggested that research in connection with the effect of channel improvement and agricultural drainage include but not be limited to a listing of completed research and existing active research on the subject, possible use of model studies, and continuation of stream flow records on areas where channel improvement or drainage projects have recently been completed. Stream flow records before and after should be of major value.

A second area where research is needed in connection with flooding is on the subject of ice jams. Ice jams are not frequently of major proportions in Minnesota and adjoining states. However, in 1951 there was one in the Mississippi River between the Ford Dam and St. Anthony Falls in Minneapolis caused by frazil ice where the water surface rose some 25 feet. Fortunately, damage was not extensive from this jam because of the area in which it occurred. In 1966 we had several cases of ice jams in Minnesota and nearby. At St. Cloud, frazil ice lodged under surface ice in the pool on the Mississippi River. Soundings showed some 12 to 15 feet of frazil ice packed between the surface ice and the bottom of the channel. Flow was confined to a relatively restricted section which remained free of frazil ice and this resulted in a steep slope in the river with flooding at the upper end of the reach. Another occurrence of ice jams this year was in the Monticello-Elk River reach on the Mississippi. Here the jams were caused by a combination of frazil ice and broken sheet ice. The first jams occurred in the vicinity of Monticello sometime prior to the St. Cloud trouble and the ice shifted several times, breaking loose and rejamming downstream with the farthest point of serious jamming being Elk River. Also last spring we had ice jams on the Red Lake River in the Crookston area. Generally these jams were caused by broken ice piling up on river banks at bends. There was also a considerably larger ice jam on the Mississippi River in the vicinity of Rock Island, Illinois. This extended for some distance upstream but didn't approach the state of Minnesota. However, it is possible that a similar jam could occur within this state. It is of interest that last week we had a minor ice jam reported on Red Lake River. The problem was reported in the agricultural area just downstream from the Indian Reservation. Water levels rose about 5 feet and caused some damage to baled hay lying on hay meadows. Fortunately the jam broke before any damage occurred to buildings. The trouble was caused entirely by frazil ice.

Research needed in connection with ice jams may include a better method of advance warning of such jams. Frazil ice forms with the right combination of air and water temperatures together with open water conditions. Ice crystals form in the open water and lodge in a downstream reach, frequently under ice cover on a pool. A system of water temperature measuring stations might be established to show when a potential frazil ice threat exists. Any warning of ice jams due to sheet ice breaking up and piling up on bridges would probably have to be in the nature of an awareness of the thickness of the ice in the stream and then a close watch on breakup conditions so that we would be prepared at the first evidence of any ice jamming. Probably the biggest area of research should be in relation to the relief of ice jams after they have formed. Any time that a jam forms it is very common for the people affected to ask that somebody, usually the federal government, dynamite the jams in order to relieve the situation. This is not always a reasonable solution to the problem, but sometimes it is effective and practicable. During our investigations last spring, we found that an explosive known as ANFO is very useful in this regard. ANFO is made up rather simply from ammonium nitrate fertilizer and fuel oil. The proper combination of these two materials causes an explosive mixture which can be combined with dynamite. The Corps of Engineers has already conducted a substantial amount of research in connection with ice jams since the 1966 problems and it intends to carry these investigations further. While the data collected during 1966 provided considerable information on the technique of ice blasting, additional data are required so that blasting can be used to more advantage and in a safer manner. Sufficient data were also collected to define the general requirements of the ice dusting technique. However because of the high costs of dusting much information is needed so that the maximum results can be attained from the efforts expended. The Corps of Engineers is investigating the possibility of duplicating field conditions in a laboratory facility. A small laboratory room with controlled atmospheric conditions is being considered. The proposed laboratory research would provide information on concentration rate of dusting material, gradation of material, and penetration rate of ice.

Available knowledge might also be supplemented to advantage by use of model studies to establish criteria regarding the action of ice at river bends. Storage of floating ice in overbank areas at river bends is one possible solution to ice jams. These models could also be used in designing river channel improvements or channel work proposed in areas where erosion by ice is a problem.

A third subject which I would like to call to your attention is the subject of flood plain regulation. While this may not be research in the truest sense, some investigation of the practicability of flood plain zoning would be desirable. If we were starting anew in developing the country, there would be fewer problems involved in enforcing flood zoning. When the country was originally settled the areas were built up along the rivers in order to take advantage of available water power and to gain lesser benefits from navigation and water supply. The settlers understood that there would be damages from flooding at certain times but they were willing to suffer those losses because of the benefits which they obtained in flood-free periods. Today when anyone is flooded along the rivers they look to some branch of government for aid. When flood plain zoning is

proposed to keep developments out of the flood plains and thus eliminate flooding, the local governments are quite hesitant to initiate such zoning because of the loss of taxes. It is understandable that they might need that area for industrial development in order to have a favorable tax base, but it seems that the area should be investigated to see if it is worth protecting in order to develop in industrially.

House Document No. 465, 89th Congress, 2nd Session, recently released, presents a report by a task force on Federal flood control policy. The report recommends research on flood plain occupancy and urban hydrology to be sponsored by the U.S. Government. Problems of flood plain occupancy would include a study of building design to withstand flooding; appraisal and design of flood plain regulation, particularly model flood plain zoning ordinances; determination of geographic factors that affect decisions to occupy the flood plain; evaluation and improvement of nonstructural measures of flood damage abatement, such as emergency evacuations; methods of putting information on flood hazard to better use in flood plain management; and study of who pays for flood losses. Urban hydrology research would include the effect of urbanization on runoff peaks from small watersheds. This problem has arisen in connection with some of our flood control studies, including those for Bassett Creek in suburban Minneapolis. Added research would certainly be welcomed here. Design of improved instruments for measuring water flow in drainage conduits, sewers, and streets are also included under recommended urban hydrology research.

The committee report also recommends that a uniform technique of determining flood frequency be developed as well as an improved system for flood forecasting. Both of these items are important for flood plain regulation, and also for general flood studies and flood fighting. Although the report does not specifically state, it is assumed that its recommendation on frequency methods pertains to peak discharge frequencies. Consideration should also be given to methods of volume-frequency determinations and to frequency determinations based on short-term records.

Methods most commonly used by Federal agencies to compute flood frequency estimates together with a complete bibliography of references on the subject are summarized in Bulletin No. 13, "Methods of Flow Frequency Analysis," published in April 1966 by the Subcommittee on Hydrology, Inter-Agency Committee on Water Resources. Research is needed to determine which methods have the highest degree of reliability for any set of conditions encountered, particularly when an attempt is made to extrapolate the curves and arrive at extreme frequency estimates. For example, the commonly used plotting point formulas applied to the greatest flood in a 100-year record, result in plotting positions or return intervals for this flood of once in 200 years by the Hazen formula, 100 years by the California formula, 101 years by the Gumbel or Weibull formula used by the Corps of Engineers. These plotting point formulas are also very sensitive to the length of record. Beard's method, for example, would plot the largest flood in a 50-year record at a 72.5-year recurrence interval, but this same flood if the largest in a 100-year record would be plotted at the 145-year point.

Variations arise when applying various methods of frequency analysis to a specific record. For the Mississippi River at St. Paul, we find that the 100-year flood based on Pearson's type III analytical method has a magnitude of 151,000 cfs for the 87 year record (1867 through 1953) including a large flood of 125,000 in 1952. When we increase the records an additional 10 years through 1963 but add no intervening high floods, the 100-year flood decreases to 139,600 cfs. When the record is extended to include the 1965 flood of 171,000 cfs, the 100-year flood increases to 151,200 cfs. If we add Beard's correction factor for length of record, the above discharges become 157,000, 144,800 and 156,400 in the same order.

Changing the method of computation has an even greater effect on the frequency estimates. Using Beard's plotting point formula, which is said to compare "very well" with the Pearson type III analytical method, and the St. Paul record through the 1965 flood produces a magnitude of about 140,000 cfs for the 100-year flood. Reducing the length of the St. Paul record back to 1958 produces a 100-year flood of 130,000 cfs by this method. It can be seen that changing the records by only 12 years and using two frequency methods with "good" comparison varies the estimate of the 100-year flood from 130,000 cfs to 157,000 cfs. If the data are extrapolated to the 200-year flood the estimates would range from 145,000 cfs to 185,000 cfs. Recently received information indicates that the committee on hydrology of the Federal Water Recources Council is currently giving further study to the matter of frequency methods.

The above enumerations are not intended to be a complete list of research needed in connection with floods. Rather, the intent was to point out areas where research is needed most in this field. Obviously we could add many more items to the list.

About 2 weeks ago I received the November 1966 Journal of the Hydraulics Division of the American Society of Civil Engineers. The Journal includes a report on "Needed Research Projects in Surface Water Hydrology," by a Task Committee on Development of Research Projects in Surface Water Hydrology. The report proposes 83 subjects for possible research projects, including some of the subjects discussed above.

Prepared Statement by Joseph H. Strub, Jr.

Robert Cowan has proposed three basic research needs: (1) The effect of channel improvements and drainage on peak discharges; (2) Ice jam formation; and (3) Flood plain regulation. Of these, I feel Item 3, flood plain regulation is needed now and is most important to Minnesota. The locations that had serious flood problems along the Mississippi River drainage in 1951 and 1952 and the Red River in 1950 were further complicated when the floods of 1965 and 1966 came because of their own doing and encroachment on the river's flood plain. With our present population growth and tax problems, all tendencies point to continued complications so that

future floods will be even more costly. Some of the problem locations are still developing flood plain areas as industrial sites, and what have you, without planning for adequate flood protection.

House Document Number 465, A Unified National Program for Managing Flood Losses, released in August 1966 and referred to in the preceding paper has two recommendations for actions concerning the flood plain: Recommendation 9, coordinating and planning new developments in the flood plain, and Recommendations 10, providing technical services to managers of flood plain property. When these two recommendations are completed and properly enforced by local, state and federal authorities, many of our flood plain problems will be lessened. The important factor, and this can be done now in Minnesota, is that industry, old or new, and the general public must be informed as to the floods of the past and their elevation in their particular community. Then, if they want to build in the flood plain, or remain, at least they will know what their chances are and what they stand to lose in terms of their own dollar loss.

In my opinion ice jam occurrence and forecasts are our next immediate practical research need. In recent years ice jam formations in Minnesota with the exception of the Red River and its tributaries, have not been a major problem. However, ice jams will be creating more of a problem because of the general public's desire to live closer to the river - places like Monticello along the Mississippi River and that reach of the Mississippi River from Elk River downstream to Fridley. In the past there was flooding along the river without extensive damage, but now this area has built up and is continuing to do so. Naturally, flood plain zoning would help but for many communities it would be too late, such areas as the confluence of the Crow and the Rum Rivers. The lower Minnesota River Valley from

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JOSEPH H. STRUB, JR. graduated from Loras College in 1947 with a B.S. in Mathematics. He attended the University of Wisconsin and the U.S. Air Force Chanute Field Meteorology Cadet Course. From 1943-46 he served in the U.S. Air Force as weather officer in Texas and Oklahoma and the China-Burma-India theater. His Weather Bureau career began at Dubuque, Iowa, in 1947. From 1948-51 he served as hydrologist at the River Forecast Center in Kansas City, Missouri. In July 1951, he transferred to the Weather Bureau Airport Station at Des Moines, Iowa, as meteorlogist-hydrologist. In 1951 he was recalled by the U.S. Air Force. His tour of duty was in Europe with his base station, Rhein-Main, Frankfurt, Germany. In July 1953, he returned to the Weather Bureau as meteorologist-hydrologist at the Airport Station, Omaha, Nebraska. In December 1953, he was assigned to the Minneapolis Weather Bureau Office. From 1955 to March 1965 he served as meteorologist in charge at the Weather Bureau Office, downtown Minneapolis, with duties as Hydrologist and State Climatologist. In March 1965, the Minneapolis ESSA - Weather Bureau Office was consolidated with the Minneapolis ESSA - Weather Bureau Airport Station. He was transferred to the Minneapolis Airport Station as principal assistant with responsibilities as supervisory meteorologist and hydrologist. He is a professional member of the American Meteorological Society and a member of the American Geophysical Union. Presently, he is on the Consulting Council of the Water Resources Research Center.

Mankato downstream is another area that has ice jam potential. The river has to be freed of snags and sand bars. Research in producing an earlier spring breakup of the ice cover over Lake Pepin would be of considerable value to southeastern Minnesota and would be an aid in reducing the flood potential downstream at Winona and La Crosse.

One of ESSA -- Weather Bureau's prime responsibilities is to maintain a flood warning system. Therefore, irregardless of what research is in progress or is being proposed by other agencies, universities, and even the Weather Bureau, it is necessary that high water and/or flood forecasts are made and disseminated. This is reality, and in itself, a real challenge. In order to make better forecasts, the Office of Hydrology is continually doing research to improve this capability. The flood warnings system consists of three major components: Observed data, forecasts, dissemination. Each phase has particular problems of its own.

Observed Data -- We depend on local people to observe, record and telephone river, rainfall and snow data in to us. Our source of observers has been the stay-at-home type and retired people, but with this modern age, we are all now more mobile and don't stay home on Saturday and Sunday. Observed data is fine Monday through Friday, but missing on Saturday and Sunday. This means we are having to go to electronic observing equipment were possible. Naturally, this will increase the cost of collection.

Forecasts -- River and flood forecasting is concentrated in 12 River Forecast Centers throughout the country. Several river districts, each with its reporting network and assigned number of forecast points, make up the area served by a River Forecast Center. The River Forecast Center consists of a group of specially trained hydrologists who process the data received from their river district offices, using objective forecast procedures based upon historical events. They take into account changing channel hydraulics, soil conditions, season of the year, and storm precipitation and duration. The manual computation of forecasts is giving way to modern digital computer methods as rapidly as resources for automatic data processing become available. The River Forecast Center that serves Minnesota is located at Kansas City, Missouri. In December, 1965, a Control Data Corporation (CDC) 3100-computer was installed at Kansas City to be used jointly by the River Forecast Center and the Bureau's National Severe Storm Forecast Center (tornadoes, etc.). On October 25, 1966, another CDC unit was added to increase its capacity. As of this date the routine forecast schemes used by the Minneapolis River District have not been programmed for the computer. The spring snow melt advisory has been completed. By the spring of 1967 it is hoped that the Mississippi River upstream for St. Paul will have been programmed and tested. The remainder of this district won't be computerized for at least another year or so.

Dissemination -- The Weather Bureau depends on the broadcast industry composed of the AM, FM and TV station facilities, as the primary method to warn the general public. Time permitting, the printed word through our local newspapers via the Associated Press and United Press wire services

is the second line of dissemination. In many instances particularly during the spring runoff period, they become one as the broadcast industry alerts the public and then they read about the potential in their newspapers. Surveys show that under emergency conditions the broadcast industry has a potential listening and/or veiwing audience of approximately 90 per cent of the population. It is hoped we get through to the other 10 per cent of the people through the first 90 per cent because of the habit that many of us have and that is "to pass on to our neighbors anything startling that we have heard or read." To get our forecasts to the broadcast industry, newspapers and other interested concerns we use our local weather teletype loops. In many cases the commercial telephone is used to contact the local official or the segment of the public directly concerned. Increasing use is being made of statewide public dissemination teletypewriter circuits, such as the combined Minnesota Civil Defense-Sheriff's loop. Naturally, communication systems of other federal agencies are used, too, as well as amateur radio operators and/or networks.

Following the disastrous 1965 Palm Sunday tornadoes, the then Chief of the Weather Bureau appointed a survey team to conduct a postanalysis and to recommend measures designed to reduce deaths and injuries in future tornadoes. After the Secretary of Commerce received this report he further directed that a more comprehensive study of all natural hazards be undertaken. Cooperation of other Federal Government Agencies was solicited in developing a nationwide Natural Disaster Warning System. This Natural Disaster Warning System, NADWARN, has been developed and funds are now being sought from Congress to implement it. When the NADWARN system is in operation, it is expected to reduce the death toll by one half and reduce by more than $100 million the annual economic losses cause by nature's violence -- floods, tornadoes, blizzards, earthquakes, etc.

To complement its river forecasting research, the Office of Hydrology has many research projects in progress that will be of benefit to Minnesota in the immediate future. A few of these are:

The development of a water-accounting model in which current studies involve the Stanford Watershed Model with modifications;

Evaporation -- Comparisons of the American Class A pan with USSR 20 sq. meter pan and other countries. "Evaporation Maps for the U.S." published in 1959 are being up-dated to include ten more years of data;

Radiation -- An improved method has been developed for computing incoming long-wave radiation as a function of air temperature, dew point and solar radiation;

Snow Research with the Agricultural Research Service near Danville, Vermont, and with the California Department of Water Resources at Twin Lakes in the American River basin. Evaluation of satellite photographs of snow cover over the Midwest;

Frequency of Rain Days -- sponsored by the Soil Conservation Service which gives the average number of days per month with precipitation of

0.50, 1.0, 2.0 and 4.0 inches or greater. This Technical Paper No. 57 has now been printed; and

Probable maximum precipitation estimates have been prepared for selected areas sponsored by the Corps of Engineers.

After you have read the preceding paper and my own comments, possibly you will conclude as I have? Although new research is healthy and is mandatory for progress, we in Minnesota already have a mightly task before us -- to clean up existing problem areas and to make a greater practical use of the research, the procedures and the facilities we already have.

Prepared Statement by David B. Anderson

In his paper, Robert Cowan makes the point that after every significant flood, statements are made that flooding was caused or greatly increased by channel improvement and drainage. I concur with him that this is a field in which research is needed in order to determine what effect these measures do have on floods. I might suggest further that the flood-protection effectiveness of different types of reservoirs and land use practices be studied. There has been little research on these

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DAVID B. ANDERSON graduated from the University of Minnesota in June 1940 with a Bachelor of Civil Engineering degree and a commission as 2nd Lt. in Anti-aircraft artillery. He entered on active duty with the Army immediately after graduation and spent about six years in military service of which 3-1/2 years were spent overseas during World War II. The anti-aircraft battery he commanded was the first American battery to be employed in the defense of London and his battery saw action in six European campaigns. In January 1946 he started his employment with the Surface Water Branch, Water Resources Division, U.S. Geological Survey in St. Paul and worked under the supervision of Paul Speer and Leon Sawyer, former district engineers in St. Paul. During this time he was primarily concerned with the collection and computation of surface water basic records in the State of Minnesota and became acting office engineer of this program. In September 1955 he transferred to Brideport, Nebraska, where he worked with a number of state employees who were concerned primarily with the collection of data which would allow proper distribution of water for irrigation purposes in the North Platte River basin. He transferred to Lincoln, Neb. in June 1957 and served as office engineer responsible for the collection and publication of basic records in that district until August 1961 when he transferred to Menlo Park, Cal. where he was engineer-in-charge of the Menlo Park subdistrict. This area included a large part of the coastal area of northern California from San Luis Obispo on the South, to the Oregon line on the north, and was the area in which the devastating floods of December 1964 occurred. In April 1963, he returned to St. Paul as district engineer of the Surface Water Branch, U.S. Geological Survey, succeeding Mr. Leon Sawyer who had retired. In this position he is responsible for the overall conduct of surface water investigations of the USGS in the State of Minnesota.

matters and many conflicting claims are made. Channel improvement and agricultural drainage are blamed for flood catastrophies for which they could not possibly be responsible. At the same time we are enjoined by some public figures to use proper conservation and land-use practices, build small farm ponds, keep the water on the land and thus prevent flooding. Can such measures really prevent floods of great magnitude?

Let us consider the 1965 flood in the Minnesota River basin; the greatest flood ever known to the white man in this valley. The area drained by the Minnesota River and its tributaries between Montevideo and Mankato, Minnesota comprises 8,720 square miles. Flood stage at Mankato is 19.0 feet and the corresponding discharge is about 30,000 cfs. For 17 days in April 1965 the discharge at Mankato exceeded flood stage and during this time 1,108,000 acre-feet in excess of the discharge which occurs at flood stage passed the Mankato gage. During the same period of time 265,000 acre-feet ran off at Montevideo and so the area between Montevideo and Mankato contributed 843,000 acre feet in excess of the discharge at Mankato flood stage. If this runoff were stored in the basin between Montevideo and Mankato, 97 acre-feet would have to be stored on each square mile of area.

The area in the Minnesota River basin between Montevideo and Mankato consists almost entirely of agricultural land of good quality and is worth about $300 to $400 per acre. If small farm ponds were constructed in this area to contain all the water above flood stage which passed Mankato in the 1965 flood, about 140,000 ponds would have to be constructed assuming each pond has a usable storage capacity of 6 acre-feet. Assuming $2,500 as the average construction cost of each farm pond, the total cost of these developments would be about $350 million. In addition, about 200,000 acres of land worth about $70 million would be removed from agricultural use. Certainly such construction would not be economically feasible. It is a fallacy to contend that small farm ponds and reservoirs can provide a solution for the prevention of floods of great magnitude. Knowledgeable proponents of farm-pond construction make no such claim. They do claim with justification that farm ponds are an important conservation measure. Proper upstream land management is very effective in minimizing the damages which occur in the many small floods of 5-year frequency or less.

In the areas of heaviest runoff in Minnesota during the 1965 flood, water was temporarily impounded in thousands of small depressions and did not run off freely because snow and ice obstructed drain tiles and the smaller drainage channels. This condition created the same effect as that which would result from impoundment of water in numerous artificial ponds and no doubt played a small part in actually decreasing the magnitude of flood peaks on some of the major streams. In many instances, maximum discharges on streams draining small basins of 10 square miles or less occurred about the same time as the crests on major streams. Observations of this flood bear out the statement of Hoyt and Langbein (Floods, 1955) that "there seems to be little evidence that over drainage basins of considerable size man has materially changed the intricate relations between the meteorologic and hydrologic factors conducive to floods, on one hand, and the resulting floods on the other hand." Further research however, would help prove this point and would induce us to bend our energies towards measures that would be truly helpful in the mitigation of floods and flood damages rather than induce us to castigate certain works of man which are not really culpable. Inasmuch as there were about $38 million dollars of damage in the Minnesota River basin along during the 1965 flood, it would seem that we should have adequate inducement to conduct some research as to the most effective flood protection measures which could be employed to minimize this damage.

The effectiveness of a reservoir decreases rapidly as the distance from it increases and so it is generally conceded by persons knowledgeable in flood control measures that upstream reservoirs cannot replace protective works downstream, but neither is the reverse true since obviously downstream protective works will not protect the headwaters areas. Research is needed to establish the best balance between the upstream and downstream protective measures in the critical flood-prone areas of Minnesota. Research which endeavors to solve this problem should also concern itself with the best land use practices to mitigate flood losses and delay the runoff in headwaters areas. Land use practices which are proposed should allow for continued high agricultural production.

I will not endeavor to expand very much on Robert Cowan's comments in connection with flooding caused by ice jams. We have ample evidence that this can be a critical problem often complicated by the presence of frazil ice. It was frazil ice that was largely responsible for the flooding in Minnehaha Creek in south Minneapolis last winter. The situation in this area was critical for a few days and it could have been much worse had meteorological conditions been somewhat different. This ice jam was minor, however, compared to some of the tremendous ones which have occurred in other areas. In the Ohio River in the severe winter of 1917-18, ice started jamming December 16 in the tortuous bends of the river between Warsaw, Kentucky and Rising Sun, Indiana. The ice jam grew steadily until it broke on February 12, fifty-eight days later. At that time the ice jam had a depth of 30 feet at its lower end and it was 12 miles in length. It backed up water more than 100 miles upstream. Ice jams can cause great damage and they are unpredictable and difficult to prevent. Research which would aid in their prevention or their destruction after they are formed would be beneficial in preventing or minimizing flood losses from this cause.

I believe Robert Cowan's third research proposal pertaining to flood-plain regulation may be difficult to implement because of the wide range of knowledge required to conduct the research and because of the controversial nature of the problem itself. The social, economic and legal aspects of the problem are inter-twined with the hydraulic and hydrologic aspects, and the solution of the problem requires the close coordination of professional people who do not normally work together. In itself, this problem points out that as our society becomes more complex, and more skills are required for the solution. I consider flood-plain zoning to be an extremely important measure in combatting the ever increasing amount of flood losses. The fact that such losses are increasing by leaps and bounds is indicated by the fact that in the 1965 flood in the

upper Mississippi River basin, flood damages were estimated to be about $160 million. In 1952, during the previous highest known flood in the basin, damages were about $20 million.

There is an injustice in our present occupancy of flood plains in that a developer who occupies the flood plain may do so expecting and receiving flood protection from the Federal government. The ordinary citizen then contributes to the cost of the flood protection although he may not be benefited in any way. Also, the ordinary citizen may purchase a residence or make other investment in a flood-plain area and be totally unaware of the risk he takes. This situation occurred during the 1965 Vermilion River flood in Hastings, Minnesota when many residents of the Westwood addition were hurriedly evacuated from their homes in the middle of the night. These homes were built since the 1952 flood, the last major flood in the area, and many residents were unaware of the fact that their homes were subject to flooding.

Continued development in flood plain areas can only lead to greater and greater flood losses even though flood protective works are continuously expanded. The only answer is a nationwide flood plain zoning procedure. Such zoning would not preclude development of flood plains, but would provide that such development would be undertaken only if it is economical to do so. It would involve mandatory, risk-related occupancy charges which would be paid by the flood-plain occupant. This procedure would discourage subsidized flood control which increases damage potential. Producing answers to problems concerned with flood plain zoning may not be research in the strict sense of the word, but nevertheless this is a field of activity in which further study is imperative. It is one of the most important activities that can be conducted today in the solution of flood problems.

Some of the other research problems mentioned by Robert Cowan such as urban hydrology and instrumentation for measuring urban flow are most appropriate. Research concerning the effects of urbanization on flooding of small urban basins should be conducted. Also, the suggestion that a more uniform method of developing flood frequencies merits further study.

In conclusion, I should like to make one final research suggestion. The business of making flood discharge measurements is arduous and dangerous work and is almost always done under adverse weather conditions. The results of almost all flood studies and the expenditures of millions of dollars for flood protection works are dependent upon the results of these flood measurements. In view of these circumstances, it would seem appropriate to carry on further research to develop additional means other than those currently utilized to measure discharge. The method now employed almost exclusively is to utilize the standard current meter which is subject to damage and inaccuracies caused by floating ice or debris which is almost always present during measurements of high discharge. Some work has been done in this area, but further research is needed.

Prepared Statement by C. Edward Bowers

Robert Cowan has very ably discussed some of the flood problems in Minnesota and the need for research in these areas. By way of review, the primary problems that he has defined are: Effect of channel improvement and land drainage on flood peaks, Ice jams and means of alleviating them, and Flood plain regulation. The 1965 floods on the Minnesota and Mississippi Rivers and the 1966 flood on the Red River exposed many people to severe flooding conditions and caused widespread discussion of these particular problems.

It would appear that flood plain regulation is the most serious of the problems listed because urban developments in flood plain areas are increasing roughly in proportion to our population. As a result the potential damage that can be cause by a flood of a given magnitude increases each year, sometimes in spite of flood protection measures. The problem is complex and involves social and political factors in addition to engineering aspects. Briefly it necessitates studies relative to; education of the public as to the need for flood plain zoning and regulation, political action necessary to initiate flood plain studies, engineering and economic analysis of urban flood plain areas, and political and legal action necessary for regulation of the flood plain.

In addition to the preceding items, research is also needed in the following areas:

Comparison of alternate flood alleviation methods -- dikes versus dams. Studies are needed of the engineering and economic aspects of dikes as compared to dams for flood alleviation in areas such as the Minnesota valley where both methods are feasible. Such studies should attempt to evaluate local benefits, downstream benefits relative to reduction of flood peaks, pollution abatement through supplementation of low-water flows, and recreational benefits. An evaluation of these factors is complex because the studies should include variations in the size or scale of the project as well as the evaluation of alternate methods. Also, the economic evaluation of downstream benefits resulting from a reduction in flood peaks may involve a consideration of flood damage

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potential for a considerable distance downstream. Similarly, benefits to be derived from supplementation of low-water flows should be evaluated for a considerable distance downstream and would involve an evaluation of sequential use of the water by various communities on the stream. Finally, the evaluation of recreational benefits associated with the flood storage reservoir could have a significant bearing on benefit-cost comparisons. The studies may show that a combination of dams and dikes would achieve the most economical solution.

Preservation of flood storage potential. -- Research studies should be conducted relative to land use around existing and proposed reservoirs, with the objective of insuring proper use of the reservoirs. The growth of recreational developments around such reservoirs results in pressure for a limitation on the range of reservoir levels. While this is understandable, it sometimes results in a restriction on flood storage. The question of public versus private ownership of adjacent lands should be considered.

Flood data collection, small watersheds. -- There is a need for additional data on peak rates of runoff, on floods, on small watersheds. A cooperative program between the Minnesota Highway Department and the U. S. Geological Survey has resulted in the collection of crest stage and discharge data for watersheds ranging in size from about 100 acres to 30 square miles. This program is in addition to regular surface water programs of the U. S. Geological Survey and should be continued.

Design criteria for floods. -- Hydrologic research pertaining to peak rates of runoff is needed to assist in the design of future engineering structures and to assist in an evaluation of flood probabilities in the flood plain. In some instances the results of such research would be applicable only to selected areas of Minnesota and in others they would be of general interest and value to many areas of the United States. Such information is needed for small structures such as culverts, intermediate structures such as erosion control and small flood control systems, and larger structures such as major flood control dams. Selected subjects in this general category include; Computer applications in the analyses of hydrologic data and in the determination of design floods, mathematical modeling of watersheds to assist in the production of design floods, physical modeling of watersheds to assist in the prediction of design floods, studies of peak rates of runoff in urban areas of Minnesota to assist in the design of storm sewers, and studies of peak rates of runoff from small watersheds to assist in the design of culverts and other drainage structures.

Research is already underway on some of the latter items but much research is needed to assist in a better understanding of the many factors affecting flood flows and thereby to contribute to unproved design procedures.

RESEARCH ON LAND AND WATER

Principal Paper by Cornelius A. Van Doren

Research on land relating to conservation and functional uses of water is exceedingly important. Most of the precipitation with which we are concerned first comes in contact with soil or vegetation. Obviously, we want to conserve this water until it can be efficiently and profitably consumed. The most important function of water, aside from the water we drink, is its use in the production of ample food and fiber supplies. Managers of agricultural and forest land not only have the responsibility to efficiently use soil water in crop production but also to protect and enhance the total water resource.

I will present only a very few statistics covering water resources and disposition. The general goals and aims of land and water research will be covered, and a few examples will be given of the type of research projects that seem to offer the most promise for effectively improving the amount and quality of useable and available water resources.

In 1960, R. L. Nace[1/] reported that less than 3 per cent of the world's water supply is available on the continents, and only about 11 per cent of this is useable or accessible. Furthermore, the yearly renewal and continued availability of this relatively minute water supply depend wholly

1/ Nace, R. L. 1960. Water Management, Agriculture, and Groundwater Supplies. U.S. Department of the Interior, Geological Survey Circ. 415.

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on precipitation from a scant amount of water vapor in the atmosphere. It is this water that falls as precipitation that can be conserved and put to the use of man until it is lost by evaporation, flows into the ocean, or is contaminated with pollutants.

The water cycle for Minnesota differs from the average for the United States. We have an average precipitation of 25 inches in Minnesota as compared with an average of 30 inches in the continental United States. Evapotranspiration losses in Minnesota are 85 per cent of the total precipitation, whereas average evapotranspiration losses in the United States are only 70 per cent. A third or more of the precipitation in Minnesota is lost through evaporation from soil and water surfaces and by transpiration from noneconomic vegetation. If this nonbeneficial use of water could be reduced by 5 per cent, about one-half inch more of the rainfall would be available for augmenting water supplies. To give you an idea of the magnitudes involved here, if one-half inch of water per year from the entire State of Minnesota were made available to stream and aquifer water-supply systems, it would provide about 700 billion gallons or enough to provide 130 gallons per person per day for 15 million people.

The goals of our land and water research should be directed toward developing water resources to serve the needs of people. We are not interested in water, per se, but in its beneficial uses by man and in its real or potential detrimental effects.

The Committee on Water Resources Research of the Federal Council for Science and Technology listed seven aims of the Federal research program:[2/]

1. To develop methods for conserving and augmenting the quantity of of water available.
2. To perfect techniques for controlling water so as to minimize erosion, flood damage, and other adverse effects.
3. To develop methods for managing and controlling pollution so as to protect and improve the quality of the water resources.
4. To develop and improve procedures for evaluating water resource development and management so as to maximize net socioeconomic benefits.
5. To understand the nature of water, the processes which determine its distribution in nature, its interactions with its environment, and the effects of man's activities on the natural processes. This is basic to the successful prosecution of items 1 through 4.
6. To develop techniques for efficient, minimum-cost design, construction, and operation of engineering works required to implement the water resources development program.

2/ Federal Council for Science and Technology. "A Ten Year Program of Federal Water Resources Research," Report of Committee on Water Resources Research, 1966.

7. To develop new methods for efficient collection of the field data necessary for the planning and design of water resource projects.

Specific Research Needs -- There are a number of specific areas where research is urgently needed if we are to most efficiently manage our water resources. The land phase of the water cycle is concerned with rain and snow that falls on the land and the path water follows in returning to the atmosphere. Critical weaknesses in our understanding of this cycle are: interception and disposition of precipitation; water infiltration into the soil and various ways to influence it; mechanisms of water movement through the soil; surface runoff and its erosive action; purity of water entering streams and aquifers; water use efficiency by economic plants; and predictive procedures on the operation of the complete hydrologic cycle.

Interception -- The kind and density of vegetation on the ground influence the disposition of precipitation. Vegetation breaks up the impact of rain, thus increasing infiltration and reducing erosion. Some precipitation is held on foliage and twigs. The patterns of forest openings affect snow accumulation and snowmelt, thus affecting amount and timing of flow. Additional work on cover manipulation is needed.

Infiltration -- Soil water supply in the root zone and the renewal of groundwater supply are dependent upon the infiltration process.

Research is necessary if we are to accurately predict the influence of land and water management practices on the infiltration-runoff processes. We are still not able to predict infiltration rates from the knowledge of physical properties of a soil. ". . . much needs to be learned before we can use the basic attributes of soil to soundly predict the nature of the pore system in a soil and its facility for water transmission under varying degrees of saturation."3/

Soil Management -- What a tremendous difference the condition of a soil surface may make in recharging the soil moistrue reservoir! At the North Central Soil Conservation Research Center, Morris, Minnesota, water intake was studied on Barnes and Nicollet soils under minimum tillage (R. E. Burwell, unpublished data). After plowing, 3.8 inches of rainfall infiltrated the soil profile before runoff started. Similar plots that were plowed but smoothed with a disc harrow absorbed only 1.0 inch of rain before runoff started. There are other practices that need to be applied. The use of crop residues as surface mulches can greatly increase soil moisture recharge. Because of the interacting effects between practices, further research is needed to develop modern soil management systems compatible with current and future commercialized agriculture.

3/ Wadleigh, C. H. (Chairman). 1965. Soil Characteristics in the Hydrologic Continuum. Report No. 1 of the Committee on Water Resources. Soil Sci. Soc. Amer. Proc. 30:418-421.

The same is true of forests and wildlands. Forests cover a significant portion of Minnesota's watersheds. The influence of forest management practices, timber harvesting systems, cutting practices, prescribed burning, and recreational uses effects the soil-water system and requires added research. Early research in Northern Minnesota forests has shown the impact of forest practices.

Water Flow in Soils -- Modern computer facilities and techniques permit solutions of complex flow systems. Several flow cases have already been solved, and significant progress has been made in checking solutions of selected cases in the laboratory and field. However, most of the computer solutions to date have dealt with problems having isothermal and homogeneous soil conditions. Recent studies by Boelter4/ have shown that flow in organic soils varies considerably by peat type and may be less than some clay soils. This information is important to the management of millions of acres of organic soils. Additional research will be required before problems can be handled that deal with shrinking and swelling soils, flow under high-energy regimes, and flow under various plant management systems on nonhomogeneous mineral and organic soils.

Runoff and Erosion -- Runoff from land surfaces and return flow of soil moistrue to surface or streamflow determine the dependability of our surface water resources. Research on land and water must be designed to insure that clean water will be delivered to aquifers, streams, and reservoirs.

In Minnesota, runoff averages about 3.0 inches annually, compared with an 8-inch average for the continental United States. Some of this runoff transports large volumes of soil. Erosion occurs as sheet, rill, and gully erosion on the land and bank erosion on streams and lakes. Deposition occurs on land and in channels or streams when runoff velocity is impeded. Erosion is a major source of water pollution.

Erosion damage to land has been long recognized, but the problem of damage to water supplies is equally important. As more streams are controlled by reservoirs, the sedimentation of these reservoirs will cause costly loss of storage capacity and shorten reservoir life. Smerdon5/, in a recent article, has aptly stated that erosion should be discussed more as a source of pollution. Research to reduce this pollution is imperative.

Future works should stress economically feasible methods of keeping sediment out of our streams and water supplies. The Committee on Water Resources Research of the Federal Council for Science and Technology believes future research should emphasize (a) an understanding of the process of sheet and rill erosion from farm, forest, range or other land areas; (b) an understanding of aggradation and degradation of streams;

4/ Boelter, D. H. 1965. Hydraulic Conductivity of Peats. Soil Sci. 100(4):227-231.

5/ Smerdon, Ernest T. 1966. Water Development and the Agricultural Sciences. Agricultural Science Review, CSRS, USDA, Vol. 4, No. 2, pp. 15-21.

(c) development of techniques for predicting sediment yield of watersheds (possibly integrated into general hydrologic models of watersheds); and (d) an understanding of the relations between streamflow, bed material, channel dimensions, and slope. Effects of cultural stress (e.g., urbanization) will require increased attention.

"Natural forces incur the movement of sediment from watersheds into streams, but the activities of man frequently increase the intensity of the process manyfold."6/

Research has not yet devised wholly-acceptable methods for erosion control under today's commercialized intensive farming practices. Thirty years ago, erosion could be held to acceptable limits by the use of sod crops. Our agriculture is geared to another production system today, with less need for large acreages of sod and forage crops. Additional research is needed on tillage, use of crop residues, use of fertilizers, use of terraces, forest land treatments, etc. A new type of land modification for erosion control and moisture conservation is being tried by the Soil Conservation Service. This structure, a grassed-backslope terrace, reduces the average slope steepness and reduces soil erosion. However, large quantities of earth must be moved to form the terrace; the natural profile of large areas of soil is disturbed; and in some cases tile inlets are required in the channel to avoid drainage problems. Research is needed to find ways of maintaining fertility, infiltration, and surface drainage when land forms are drastically modified.

Clean Water Supply -- A major goal of watershed protection is to deliver high-quality water to streams and to groundwater supplies. We know a great deal about the control of erosion and sedimentation, but we need a better understanding of the application of known concepts to current and future land management systems.

Agricultural chemicals and pesticides are potentially a source of pollution in water supplies. Little is actually known about the fate of pesticides in soil. Limited studies are now underway to determine the quantity of pesticides in sediment and runoff.

Nitrogen is becoming cheaper with improved processing methods. Research should determine whether there may be a maximum level of applicable nitrogen beyond which our water supplies would be endangered.

Research is badly needed on efficient disposal methods for animal wastes.

Research should determine present water quality trends in our wilderness lakes and provide guides for maintaining water quality to meet mounting recreational use.

6/ Wadleigh, C. H. (Chairman). 1965. Soil Science in Relation to Water Resources Development: 1. Watershed Protection and Flood Abatement. Report No. 2-I, Committee on Water Resources, SSSA Proc. 30:421-424.

Efficiency of Water Use -- Modern production practices and improved plant varieties have brought about a system of agriculture that is much more efficient in the use of water than practices and varieties in common use 25 or 30 years ago. However, research can further improve the consumptive use of water by economic plants. First, we can alter the plant environment. Research on management practices such as tillage, plant flood application, feeding methods, and rates and dates of seeding are examples. In forest management, research is needed on site preparation and plant density levels. Simple modifications of the micrometeorological environment may also increase efficiency of water use. Here there is a great need for research on the energy balance relationships of forest and crop lands. Another way to increase water use efficiency is by breeding plants for drought resistance and increased efficiency of water use. Advances can be greatly accelerated once the responsible characteristics are understood.7/

Watershed Studies -- Experimental watershed data have been helpful in the development and testing of computer models of the hydrologic cycle. Data from one watershed cannot directly transferred or applied to another because of differences in watershed characteristics such as size, shape, slope, time of concentration, and hydrologic soil-cover complexes. Computer models can be no better than the completeness of the input data. Subsurface phenomena, which may involve soil water recharge in the root zone, return flow, and groundwater storage, need to be evaluated. The projection of theoretical concepts, models, and numerical equations will need to be evaluated in both laboratory and field research studies.

Conclusions -- The ultimate goals in managing our water resources is to assemble established principles and facts into a meaningful predictive procedure; i.e., a systems-analysis should be applied to water management. For only then will we be able to maximize the economic, social, and intrinsic use of water to the betterment of all our people.

As we further attempt to control our environment, we must deepen our understanding of the effects of control on natural and physical phenomena. In this way only can we avert disaster. Research thus far has given us a modern agricultural technology that permits one man to feed 33 of his neighbors. Land management practices on our forests and agricultural lands are the basic modifiers of our environment and water resources. To control the direction of change for the ultimate benefit of all the people, there must of necessity be research. With the tremendous background of scientific knowledge available, research should be opportunity-oriented. This type of research ". . . centers in science and looks towards the way scientific projects can serve needs rather than starting with needs and looking at how science can serve those needs."8/ To

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7/ Burton, Glenn, W. 1964. The Geneticists' Role in Improving Water-Use Efficiency by Crops. ASA Special Publication Series No. 4, Research on Water, pp. 95-103.

8/ Brooks, Harvey. 1966. Organizing Research for Social and Economic Objectives. Agr. Sci. Rev., CSRS, USDA, Vol. 4, No. 2, pp. 37-39.

accomplish this objective, more fundamental research is needed. The theories and concepts developed in the basic sciences can help serve the research needs on land and water.

Prepared Statement by William P. Martin

It is a pleasure to serve as a member of this conference on water which is basically being held to meet the rapidly developing demand on the part of the Minnesota public and our scientific colleagues also, for water information. For water is now recognized as perhaps the most essential of our natural resources which is often in short supply and anything that relates to an understanding of water in the complex natural environment in which it serves as a dynamic unifying substance, will be of general interest.

Cornelius Van Doren and Herbert Flueck, my colleagues on this panel, have superbly illustrated the way in which many disciplinary groups are approaching and must be concerned with water both in its natural state and as modified by man, its essentiality to plants and thus to agriculture and forestry, and the way in which the natural environment of plants, that is, the soil and associated microclimate, accommodates and utilizes most of the water reaching the surface of the land. In the competition for water resources, it is essential that we understand how to minimize losses, assure beneficial uses, and greatly increase utilization efficiencies. Research will provide solutions by objective experimentation and evaluation and education will assist in assuring that society's needs are accommodated.

WILLIAM P. MARTIN is Professor and Head of the Dept. of Soil Science at the University of Minnesota. He was born in Utah on July 15, 1912. He was first employed as a Research Fellow at the Iowa State University, Ames, where he obtained the Ph.D. degree in Soil Science in 1936. Subsequent positions have included the University of Arizona, Tucson; The U.S. Regional Salinity Laboratory, Riverside, California; the Southwestern Forest and Range Experiment Station of the USFS, Tucson, Arizona (Chief, Div. of Watershed Management); and the Ohio State University, Columbus, where he served as Professor of Agronomy and of the Soil Conservation Society of America. He has served as secretary of the Western Society of Soil Science. He is the immediate past-president of the Soil Science Society of America and serves on the executive committee and also of the American Society of Agronomy. He is a member of several other scientific and honorary societies as listed in Who's Who in America. He currently heads a department of some 30 senior staff members including Federal and Branch Station soil Scientists and 35 graduate research assistants. He is "collaborator" with the Upper Midwest Soil and Water Research Laboratory, ARS-USDA, Morris, Minn., which includes a basic research team assigned in the department studying the problem of soil structure-organic matter relationships. He has served recently as a member of the Pesticidal Residues Committee of the National Academy of Sciences Discussion group meeting on the International Biological Program. He is on the Advisory Committee of the Minnesota's Water Resources Research Center

In this latter context, I must say a word about conservation. We have been able to effectuate and continue a most remarkable economic growth in this country without being too concerned about our natural resource base. However, it is now abundantly clear that we must take cognizance of the dissipation of our soil and water resources if we are to meet the needs of the future. Water shortages, spectacular floods, erosion, and sedimentation and other forms of pollution, are becoming generally recognized as serious and as factors which do alter our way of life. We are thus beginning to get a larger share of the needed research dollars from legislators and other groups to systematically and objectively approach the problem of conservation according to the concept of "proper" and "efficient" use of resources so as to afford better cooperation between man and his natural environment. We have made progress in improving the efficiency of water use only as fast as we have gained knowledge about water and its manifold relationships, and we must obviously rely more and more on research to provide the facts upon which we must base our utilization programs.

The amount and the quality of water available for use depend in large measure on the effective management of the soils over which and through which the water must flow. Conversely, the stability and productivity of soils depend in a major way upon proper conservation and management of water. It is appropriate, therefore, that the efforts of soil, water, and plant scientists and those in related disciplines be combined in the research and educational efforts needed for presenting the case for water in its relationship to the land.

Agriculture and forestry which so far have had first call on the nations' water supplies because they occupy most of the land surface, must increasingly justify their use of water as pressures grow for urban oriented uses. We must, therefore, assure the greatest efficiency of water use for growth of plants, and we must also assure that these minimize the pollution that comes from soil erosion, from the residues of pesticidal chemicals, from the leaching of nutrients into lakes and streams and into underground water supplies where they may be harmful.

Water used on farm lands is mostly for the production of crops and that dissipated in the forest is essential for the growth of timber or for recreation. However, maximum economic benefit from such uses is contingent upon good soil or plant management, adequate fertility, use of proper varieties, pest control and other management factors. Stated in another way, evapotranspiration will be about the same irrespective of yields so that it is important that we strive to maximize yields or improve quality so as to increase water use efficiency and improve our justification for such uses.

Minnesota, as in the rest of the nation, showing a steady decline in farm numbers, though farms are becoming larger and they are more highly organized as business enterprises. They are also more susceptible to economic troubles through mismanagement. Since the available supply of water for crop production is a major determinant in yield and profits, cognizance must always be given to the vagaries of weather. Removal of excess water from poorly drained soils is sometimes needed and drainage methodology still constitutes a research requirement in our heavy-textured soil areas, such as the Red River Valley. However, precipitation is mostly inadequate for desired production levels and soil management researchers must be directed towards increasing the infiltration rates of water into the soil profile which serves as the storage reservoir for water used by plants. It is evident that information is needed on precipitation statistics and probability patterns and that irrigation programs should be instituted where feasible.

Even though farm sizes in Minnesota are increasing, as noted above, total cropland harvested is decreasing, at least during the last 10-15 years. These decreases have occurred largely in the areas of low fertility and droughty soils in central and northern Minnesota. The economy of the local areas has been adversely effected and other enterprises like forestry and recreation have not expanded to improve the situation. However, it is possible with technical information currently available to institute irrigation, improved fertilization and tillage practices on these marginal sandy and associated peat soils. And there is demand for processed vegetables, sod, cranberries and crops like barley, potatoes and soybeans which can be controlled in quality, and which can be readily grown on these soils. Forest land enterprize can also be improved and complement farm activities by bringing modern soil and water management technology to bear on these presently underdeveloped lands. Research must remain strongly in the picture and the multiple use aspects of available water supplies accommodated.

In summary, and though not wishing to be repetitive in the elaboration of research needs, may I briefly list several areas for emphasis where research activity is necessary if Minnesota is to continue to show the high efficiency of utilization of its soil and water resources.
1. Intensified soil survey investigations to provide an inventory of soil resources essential for land and water planning and development. 2. Accumulation of macro- and micro-climate data including precipitation patterns, solar radiation, temperature and probability forecasting.
3. Studies to provide quantitative information on soil-water-plant relationships for major Minnesota croplands and forested soils and field intensification methods to improve water use efficiency. 4. Research on watershed protection and management procedures including land treatments and structural measures as correlated with production economics and stream pollution. 5. Surface and sub-surface drainage of heavy-textured soils and investigation of saline soil and water problems in western Minnesota. 6. Irrigation methods and procedures on Minnesota sandy soils and peats where feasible and multiple use supplies adequate.
7. Studies in general that will provide knowledge of the irrigation requirements of forage and cultivated crops under various atmospheric, soil and crop management conditions. 8. Researchers on the water storage capacities of key Minnesota soils for plant use with research on structure, compaction and tillage methods to increase infiltration and also as related to runoff, erosion and sedimentation. 9. Development of procedures designed to moderate the high evaporation losses from both cropped and bare soils and examination of the "fallow" in western Minnesota. 10. Plant breeding and selection of varieties to maximize yields and improve quality for given water supplies and also to withstand drought.

Finally, may I conclude by suggesting that a shortage of well trained and educated natural resource, including soil and water, scientists and engineers is and can be increasingly serious if we are to meet the challenge of our water problems. We must attract and train more young people in the many disciplines that have been noted as being relevant to the field. We must also support and expand our continuing education efforts so as to make available to the planner and land manager alike the latest research information which can only be useful as it is put into practice to afford a sound program for water utilization, management and conservation.

Prepared Statment by Herbert A. Flueck

Agriculture is the first large user of the water that falls on the land. Agriculture must therefore assume the responsibility for efficient and economical use of this water, passing the surplus on to the next user in an acceptable condition. In Minnesota, the efficient and economical use of water in agriculture will involve the use of soil and water conservation practices such as, cropping systems and soil management pactices such as, cropping systems and soil management practices designed to improve the infiltration rates of soils, terraces, farm ponds, wildlife wetland development, reservoirs for floodwater protection and recreation. These practices provide for better use of water and reduction of loss by runoff. How will this be accomplished?

The Soil Conservation Service of the Department of Agriculture was organized in 1935 by congressional action and charged with the responsibility of providing technical assistance to farmers and landowners in the planning and installation of soil conservation practices on the land for the purpose of reducing erosion. The original objectives were primarily directed toward controlling erosion. It soon became evident that water was also an important resource that should be conserved as well as controlled. The objectives were changed to include the conservation of soil and water. Our work is carried out primarily through locally organized soil and water conservation districts in accordance with the terms of a Memorandum of Understanding. In the early years of the conservation movement little was known about soil conserving practices so it was

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necessary to improvise. The need for more research to explore and develop ways and means of controlling soil erosion and conservation of water soon become evident. A special research program geared to get the answers to soil and water conservation problems was set up by the SCS in cooperation with the State Agricultural Experiment Stations. In recent years this research effort by the SCS was transferred to the Agricultural Research Service of the USDA where research is being continued in close cooperation with the State Agricultural Experiment Station. Under this arrangement much progress has been made in the development and refinement of soil and water conservation practices.

We cannot rest on our past accomplishments. Much more information is needed to keep up with today's needs. Farming methods are changing, new machinery is being developed, improved seeds and plants are being introduced, fertilizers and pesticides are being used, all of which will increase production. This in turn will increase the pressure on the land and require a greater need for soil conservation practices and water management. To be effective, research must look into the future and anticipate the needs. More information is needed. Research will provide the solution to many of the problems.

One of the many important activities being carried out by the SCS is that of the small watershed program. Plans for watersheds are prepared to give protection from floodwaters, erosion control, development of recreation, fish and wildlife habitat and complete land resource development. To properly develop this kind of plan one of the first problems that confronts the watershed engineer is to be able to predict the amount of runoff he will have to deal with in preparing the watershed plan. For most topography, methods have been developed to provide the amount of runoff. In Minnesota we have large areas of flatlands interspersed with swamps and lakes. Methods presently used give a wide range of answers. More research is needed to establish a method of determining runoff based on flatland topography for watersheds ranging in size from 15 to 50,000 acres. This method should provide for predicting the following information: maximum discharge, total volume of storm runoff, and annual runoff.

The control of erosion is one of the basic objectives of the SCS. This item is still one of the most important problems to be solved. Soil lost from the farms reduces fertility and increases the pollution of our reservoirs and streams. More accurate procedures are needed to guide technicians in estimating the per cent of gross erosion that is actually delivered to proposed structures, and information is needed on the rate of storage lost by sedimentation and economics of restoration of natural lakes and reservoirs.

Irrigation is expanding in Minnesota and many questions need to be answered. Research is needed on: Underground water supply and the quality of water; water intake rates of soils under different cropping systems, tillage and residue management for economical and safe use of water; an accurate and simplified method of determining soil moisture conditions for guiding application of water; the economics of irrigating vegetables, general farm crops and pastures; rates, types methods and timing of fertilization where crops are irrigated; effect of water temperature on crops; and cropping systems for intensive truck cropping program.

Drainage is a very important practice used in Minnesota. Even though we have years of experience in the use of this practice, we find that changing conditions and methods of farming are raising new questions. Studies are needed on such practices as bedding, land grading and land smoothing to improve surface drainage, particularly in the Red River Valley. In the field of tile drainage better information is needed on: Infiltration, transmission rates, use of a drainage coefficient of less than 3/8", and drawdown curbs on key wet soils.

Much of Minnesota's woodland is on low wet land. Research is needed to determine the relationship of tree growth to depth of water table. It is known that excessively high water table reduces tree growth but additional information is needed to determine the optimum height of the water table for best production of various tree species. Also, continued research is needed on the hydrology of wooded areas, including bogs.

In the field of engineering design, information is needed to determine the most efficient and economical method of sealing farm ponds and other water holding structures to prevent loss of water by seepage.

With rising costs of construction, we need to know more about the suitability of new materials for use in constructing low cost structures for erosion and water control. Terraces are one of the most effective methods of controlling erosion on cropland. Terraces are planned with three general objectives in mind -- erosion control, farmability, and topography improvement. The grassed back slope terrace is one type that meets these objectives. The grassed back slope terrace uses a conduit outlet to carry the runoff down the slope thus eliminating the need for waterways. This type of terrace and the conduit outlet have been developed by field trials and experience. Research is needed to evaluate this type of terrace, the best design of conduit and the most effective spacing.

As mentioned in the beginning, agriculture must assume the responsibility for passing unused runoff on to the next user in an acceptable condition. The question then becomes, what is an acceptable condition? Fertilizers and pesticides are being used more and more by agriculture. We need to know more about the makeup of runoff as it leaves the farm and enters our streams. The list of questions and information needed to keep up and forge ahead with modern agriculture goes on and on. As one problem is solved, new problems present themselves. Research is a continuing search for new and better ways to effectively and economically use our natural resources.

Prepared Statment by John R. Borchert

Cornelius A. Van Doren concluded with the statement that continuing research on land-water relationships should center in science and look towards ways in which it can serve needs, rather than begin with needs and bend science to serve them. I agree with this, provided that the term science includes the systems analysis needed to apply our fund of knowledge to places and regions as they exist. Two examples of long-term opportunities for such application come to mind.

The glacial drift plains of southern and southwestern Minnesota are some of the richest farm lands in the Middle West and in the nation, partly because of their legacy of natural conditions and customs, partly because of continued investment in improvement of land and physical plant. This continued competitive improvement and intensification of Midwest agriculture, I believe, is eventually going to lead to widespread use of supplemental irrigation.

The master river of the south central region is the Minnesota. Despite its impressive valley, it is a small prairie stream. As Cornelius Van Doren pointed out, between 85 and 95 percent of the rain that falls on that part of the State goes to evapotranspiration. But much of that water is not wasted. For the land is 70 per cent cultivated, and some substantial fraction of the evapotranspiration from the cultivated land is essential to crop production. Some claim that this enormous water need for crops imposes a severe and perhaps impassable limit on future food production and population. The total runoff from the southern and southwestern prairie region of the State equals 5 to 14 per cent of the total evapotranspiration. Thus, an increase in the efficiency of water use by crops, of the order of ten percent, could probably equal the maximum amount of supplemental water that could ever be brought to bear for irrigation in the region. This points up not only the need for better understanding of water use efficiency by plants, but also the need for a systems analysis which shows where the water is most readily available and where it is most profitably applied. Into this analysis, in turn, must go not only the kind of improved data on soil porosity and permeability for which Cornelius Van Doren has called, but also research on the social and economic aspects of land management. For example, the rapidly increasing farm size in our main farming region is, of necessity, accompanied by rapidly increasing fragmentation and physical separation of individual parts of any given operating unit. Farmers typically operate holdings which are separated by 1 or 2 miles or more. Does this reduce their ability to apply modern water and land management techniques? Is the reduction significant in the long-run agricultural economy of the Midwest?

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Let me turn briefly to another example. The population growth of this part of the United States is concentrating in the Twin Cities metropolis. It is likely that the number of people living here will double by the end of this century and their water requirements will more than double. To preserve the quality of the Mississippi River below Red Wing, let alone restore the quality of it above that point, more water is likely to be needed to augment natural low flow, regardless of what else may be down. There are at least two ways in which to augment the flow: (1) allow greater drawdown from present storage in the Headwaters lakes, or (2) provide more storage. Research might well disclose other ways. But let us examine those two.

Greater drawdown must be considered within the framework of a system of information including more knowledge than we now have assembled concerning lake shore development trend and outlook, who is affected by drawdowns, how much and over what period of time. On the other hand, the creation of more storage capacity must be considered within a framework of knowledge about how much reservoir land is available, where, at which price, and how it fits into the pattern of needs for cultivated land and timber land. A sizeable part of the Mississippi River above the Twin Cities was, in late glacial time, temporarily a lake. Much of that lake bottom today is almost unused and very sparsely settled. A Texan who was buying some of that land recently is reported to have said, "It doesn't cost me but $2.50 an acre--land's worth that much just to hold the world together." Looking at land and water research at the geographic scale, how does that land fit into the water needs of this region in the foreseeable future? Would it best serve this region as a lake again? Or should the necessary storage be developed underground? Useable storage capacity in the glacial sand and gravel and the sandstone bedrock beneath the metropolitan area may well equal the potential of a new surface reservoir equal to the size of Leech Lake. Is it a feasible substitute?

In conclusion, let me underscore once more the points Cornelius Van Doren has made regarding the need for a direct approach to the measurement and widespread description of the physical properties of soil and the water-use efficiency of plants. And let me urge once more that this knowledge be put into an analysis of the man-environment system which will give it ready application.

RESEARCH ON LAKES AND WATER-BASED RECREATION

Principal Paper by Jerome H. Kuehn

Perhaps the first step in this discussion is to define what is meant by research on lakes and water-based recreation. My elected definition may be somewhat restrictive because of my interpretations and perhaps also by my limited viewpoint. In this presentation I have limited my discussion to that research which is recreation-oriented and that type involving lakes, streams and other bodies of water. Rather than attempting to cover the broad research on lakes including geology, hydrology, and many other disciplines I have narrowed this topic to the extent that research on water resources or its uses would affect the recreation user of our states' waters.

Water-based recreation is most important to us in Minnesota not only because of the numerous natural lakes and streams but because of the attractiveness that it presents to the present and will present to future generations. Already, we know that participation in such activities as fishing, swimming, boating, canoeing, water skiing and skin diving includes a large majority of our resident population. For example, 42 percent of Minnesota residents buy a license to fish. Recent surveys reveal that about one-half of our residents go swimming and do so on an average of about 15 times a year. Add to this the anticipated increases as predicted by the Outdoor Recreation Resources Review Commission and the importance of recreational use of our water resources can be easily seen.

During this discussion it will be detected that there are two categories of research being discussed. The first is research pertaining to the resources on which certain recreation is based. The second category dwells on research relative to the user or those recreational activities based on water. It will be apparent as we progress on this subject that the resource - and the user - research have a definite inter-relationship. Increasing competition for resources and mounting pressures have brought us face to face with realities of the needs to

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reach optimum integration and allocation of resource users. Outdoor recreation has most certainly triggered the interest in the relationship of resources potentials.

History of Lake and Water-Based Recreation Research in Minnesota

Before discussing current research in this field let us look back on the various types of lake and stream investigations where we find that, like most other states in this country, the research consisted of the exploratory type. With the impetus of the taxonomic system developed by Linnaeus these early studies were largely limited to collection, identification and cataloguing of various forms of aquatic fauna. Some of the most complete collections date back to the turn of the century when Cox and others explored the waters across the State. About this time certain workers such as Adams and Hankinson, Forbes and Richardson worked on the life history of fresh water fishes many of which are found in Minnesota.

Later, using methods and techniques developed largely by Wisconsin's Birge and Juday, workers began exploring the limnological features of our lakes, primarily, in the late twenties and thirties. Many basic differences between the waters and their biota were then noted leading to another phase of investigation, the inventory and classification of lakes.

Perhaps the most extensive investigations of our lakes and streams has been the lake and stream surveys first conducted by Dr. Eddy at the University of Minnesota and later by the Department of Conservation. Although carried on over the past thirty years in various intensities this has not been completed yet. However, information on the physical, chemical and biological characteristics has been collected analyzed and compiled on over 2,500 lakes.

Such inventory of our lakes together with evaluation of their potential has been invaluable as a basis for fisheries resource management since this is the purpose for which this investigation was intended. These lake surveys as well as stream surveys were found to be most useful as a management plan but because of their synoptic nature were not designed to solve the various fisheries problems.

As the problems associated with fish and waterfowl, and other aquatic wildlife became more significant more definitive research work has generated largely by the State and Federal Conservation Agencies. Since the 1930's, when much of this began, until today a considerable volume of research work has been carried out with the Universities also contributing largely in the last 15 to 20 years.

Research on Lake Resources

The research on lake resources as conducted to date has been difficult because of the fact that one could seldom isolate the fish, wildlife species or other organisms and conduct tests using the many environmental factors affecting the species in its natural waters.

Techniques for measuring size of populations with a fair degree of accuracy are still weak. However, in recent years fisheries research work has uncovered several important facts among which the following are most notable: that each body of water's biomass is dependent upon water fertility; that each species in a lake fluctuates in numbers from year to year, Primarily because of variable-sized age groups in the population; growth rates, are slower in the northern latitudes thus reducing the maximum sustained yield rates; in many cases angling is selective of only a few species and of these only a segment of the population being of acceptable size; yields of certain more desirable species such as walleye may be near the maximum in many lakes; the physical and chemical make up of lakes through the aquatic habitat provided determine the types and to some extent the amount of each present; that the "average" lake in Minnesota yields about 15 pounds of fish per acre to anglers who spend an average of 30 hours per acre to take them; that each lake consists of a different habitat complex and resulting flora and fauna making it desirable to manage each lake separately insofar as possible; and that any change in water quality, watershed runoff, shoal soils, competing fish species, for example may influence a fish population in its size or growth.

Of course, the above selected findings make up but a small part of the new knowledge gained in this field. Also, should anyone feel that this field is well advanced one only has to learn that fundamental knowledge on certain phases of life history, reliable techniques for counting fish or waterfowl in or on our medium or large lakes, assessing the success of natural hatching and rearing of the important species to name a few research needs are for the most part still lacking.

Looking toward aquatic wildlife research it is readily seen that knowledge of waterfowl, muskrat and beaver and their relation to lakes and streams has been gathered through many in situ studies and the complex inter-play of outside factors have been difficult to assess. For example, the food habits, the migration patterns, nesting and other facets of life history are well documented. The influence of changes in aquatic vegetation, changes in nesting facilities, hunting pressures are just now being studied in spite of the inability for the worker to control influences.

The biologist is constantly faced with the problem of studying the entire ecological sphere in which the species he is concerned with lives. Add to that the frustrating situation in that each significant event in the life history of a species occurs but one each year.

Up to this point, I have not hardly mentioned the many research studies on water quality, on limnology, on aquatic botany, aquatic entomology or others all of which have an integral and necessary function in gaining the knowledge of the entire eco-system needed for its proper management. Perhaps others will touch on some of these studies.

To sum up the biological research on lakes and streams one might say that we now know what types of habitat are needed to maintain certain

fish and aquatic wildlife, but quantitative data are lacking; we can measure harvest but standing crops are in many cases only roughly estimated; we know that changes in water quality affect fish and wildlife in some cases but to what extent and under what circumstances remain to be determined.

Research on Water-Based Recreation

Now to take a look at the other end of this topic of research in water-based recreation or at the user. This is the product, outdoor recreation defined as an activity undertaken because one wants to.

Organized research into the problems of outdoor recreation has been limited for several reasons. Perhaps the most important is that recreation simply has not been recognized in most professions as a respectable field for scientific inquiry. Perhaps another reason was that up until recently the recreational uses of our resources were not too demanding. Furthermore, recreation as a product has only possessed asserted values and considerations not easily subject to analytical research. Being an activity generally provided by public bodies there is a general absence of past market and cost data. Add to this the fact that there has been no research institution organized specifically for outdoor recreation research and you can see that this is an "open field" for research work.

Research in outdoor recreation is definitely of concern to use in our study of water resources. To be both meaningful and useful, research must consider both the resource and user as mentioned earlier. This research is on recreation which is resource-based rather than user-oriented such as in the case of that in city parks.

I will now discuss some of the broad categories of research on water-based recreation particularly those dealing with recreational use and activity, resource evaluation, carrying capacities, allocation of natural resources for outdoor recreation, economic impact, pricing methods and financing of outdoor recreation.

Water-based recreation is interpreted here as those aspects of outdoor recreation where the water resource is the primary attraction. Any discussion of this type of recreation should include such activities as fishing, boating, canoeing, swimming, waterfowl hunting, aquatic bird watching, nature study, scuba or skin diving, and water skiing. These activities are so-called water-contact type of activities in contrast to those which may draw on water resource for some of their value but which can be carried out irrespective of bodies of water. The activities referred to last may include camping, picnicing, driving for pleasure and most other outdoor recreation activities which are to some extent enhanced by but not dependent on water.

Summarized below are some of the more significant research studies on water-based outdoor recreation.

Survey-type Studies -- Numerous surveys of various types are carried out, usually to inventory the resources of the area, gather pertinent facts about the user and the use of the resources with an aim toward assisting developmental analyses and projection of potentials. These studies usually point out the needs and problems for which information must be acquired through research.

An example of such a survey-type study was that carried out on the Superior National Forest pertaining to the canoeists and boaters in the Boundary Waters Canoe Area.

Another example might be one of the fishing censuses now conducted on Mille Lacs Lake or the Mississippi Boundary Waters.

Resource evaluation -- This type of study consists of setting up a yardstick by which one can measure one area against another. Research on this has been done elsewhere and will soon be tested in this state to make appraisals for outdoor recreation potentials. Although designed primarily for private enterprise it might well assist the agency administration with formulae to use in his decision-making process where development of new water-based recreation may be involved.

For example, it will be very desirable to be able to measure either quantitatively or subjectively those features which would enhance or detract from a potential water impoundment. Water temperature, degree of water pollution, effect of drawdown and other known features should be given some weight in choosing a site or type of development. More data on the attitudes of potential users is needed.

Carrying capacities -- Perhaps one of the most extensive types research being carried on is that of determining the potential sustained carrying capacity levels in the case of fishing. Here, the use is directly tied into the resource in that the carrying capacity for this activity is determined to a large extent by lake types and in turn productivity. For example, it has been documented that the fishing carrying capacity is far less in the northeastern lake trout lakes than in the southern panfish lakes. One aspect that needs further refinement in this matter is satisfaction. At one time this was the only measure used but we now realize that angler satisfaction may be dependent on many things of which the angling success may be the major contribution. And this will vary with the type of trip made, being more complex on the more scenic clear-water lakes of the north while more dependent upon fishing success on the shallow turbid lakes in a predominantly agricultural area.

In terms of recreation such as canoeing, for example, there are other qualities of the trip which determine satisfaction in the minds of the users. Other users or uses often compete with one another thus limiting the actual carrying capacity. Work in this field, started but a few years ago, must continue until the administrators are capable of knowing how to allocate the natural resources and maintain the highest sustained recreational use consistent with the quality desired.

Allocation of natural resources for outdoor recreation -- The multiple-use concept has demanded a growing recognition particularly

since the current pressures for outdoor recreation descended on the resource scene already pre-empted for other resource needs. Research work in this area must attempt to solve the many problems resulting from multiple users of the same resource. For example, the six Mississippi headwater reservoir lakes have served as reservoirs for supply of water for downstream navigation including log drives, for some of the best walleye angling in the state, for wildrice production and more recently for highly developed shoreline recreation, pleasure boating and other activities. As the demand for more flood control operation, more downstream supply of water for municipal needs and other water-supply demands arise there will be a need for more research on approaches toward properly allocating and integrating all uses including the recreational uses of the resource. As we will mention a bit later the administrator may and should consider social as well as economic values in doing so.

Economic impact -- The economic impact of water-based outdoor recreation in Minnesota is now more than of intellectual interest to many people. As the costs of providing additional areas grow larger the economic benefits will take on a sharpened importance. There is much interest in trying to use outdoor recreation opportunity as an economic support to depressed rural areas. We have heard the comment that after this water project is constructed the private landowner-investors cannot fail in the fact of the impeding recreation pressure." One could ask the question of how much income potential an investor really possesses for the privilege of fishing, boating, swimming, etc. There is also a definite need for research into the extent that recreational developments stimulate local economies. Valuation of recreational benefits is a problem that we will hear more of in the future and we should be busy in researching the answers.

Pricing methods and financing of water-based outdoor recreation -- In general there is a growing belief that recreation can and should stand on its own feet - that those who request and use special facilities should pay for them. Samuel T. Dana, Dean Emeritus of the University of Michigan has said that "in the absence of a free, competitive market the supply of different kinds of recreational opportunities and facilities that will be provided, and the prices that will be charged for their use, are controlled by different factors than those that control the price and the supply of guns, automobiles and other commodities." He also went on to say "Legislative and administrative decisions on these points are apt to be influenced strongly by social as well as economic considerations, particularly in the case of lands in public ownership." Research is needed to assess the social values as well as the economic values.

If I have ended here with a pot-pouri of seemingly complex problems then I feel that I may have correctly described the dilemma that administration in the field of outdoor recreation face. Researchers are needed to solve these problems and they must be economists, biologists, recreationists, foresters and others working in their respective disciplines but somehow bringing their knowledge to bear on outdoor recreation. Research on our lakes and water-based recreation should continue so as to provide the means of maintaining the resource and the diversified recreation it can produce and serve to guide today's administrator facing this new outdoor recreation development. And these administrators and the agencies they serve must realize this need and allocate sufficient time and funds. Everyday. The administration of these resources becomes more complex and it becomes apparent that existing knowledge will certainly not be sufficient to give this resource use its proper perspective.

Prepared Statement by Joseph Shapiro

At a recent meeting of the Minnesota Outdoor Recreation Resources Commission at Detroit Lakes I outlined some of the research which the Limnological Research Center is doing on the Lakes of Minnesota. I pointed out that our approach to problems of abundance of aquatic nuisance organisms, such as rooted aquatic plants and algae, is one of attempting to determine the cause, whether natural or man-made, of heavy growths of these plants. That is, rather than carrying out research on new herbicides to alleviate the problem, we feel it will be more profitable in the long run if the growth can be prevented in the first place. Thus, we are studying the lakes in several ways to see what makes them tick, so to speak.

For example, we are doing studies of the productivity of lakes about the State to determine whether there is a geographic pattern--whether in certain areas lakes are very productive as contrasted with other areas. In this way, and through studies of the chemistry of lake sediments, we hope to be able to determine whether in a given situation we are faced with a long-standing problem due to natural circumstances, or one of recent origin caused by the activities of man.

We are conducting several different types of studies on the use of phosphorus by algae in lakes, as phosphorus is one of their prime nutrients, just as it is for corn or other crops. One of the ways in which man's activities results in aquatic nuisances is through the increase in the phosphorus supply to a lake through waste disposal, agricultural runoff, or other sources. Thus, we are studying whether the same quantity of phosphate, added perhaps as sewage effluent, will cause the same increase in growth of algae in different lakes, or whether there are, as has been suggested by others, factors that allow the phosphorus to be used more efficiently in some waters than in others.

JOSEPH SHAPIRO received a BSc from McGill University in 1950; a MSc, University of Saskatchewan in 1952; and PhD (Zoology), Yale University in 1957. He was Research Associate at the University of Washington from 1956-1959 doing work on sewage fertilization of Lake Washington, geographical variations in coloring matter of lakes, and the phosphate-sparing factors. He was Assistant Professor at Johns Hopkins University from 1959-1964 and worked on phosphorus compounds in sewage effluents, and methods of removal. He is Associate Professor, University of Minnesota, doing work on relation of yellow coloring matter in lake water in inorganic constituents and to the availability of phosphate for algal growth. He is at present Associate Director of the Limnological Research Center, University of Minnesota.

Other investigations deal with trace-element concentrations, with distribution of diatom algae, and with the nature and roles of the dissolved organic substances of natural waters.

All of these are what we would call fundamental studies, aimed at understanding the situations. In many cases such an understanding can lead to the proper remedial measures and consequent improvement. Such a situation occurred in Seattle, where Lake Washington, fertilized by sewage effluents, began to develop immense crops of objectionable algae. Warned in time, largely thought the efforts of Professor W. T. Edmondson of the University of Washington, Measures were taken and the lake seems now to be on its way to recovery.

However, in other cases even a complete understanding of the problem might not help. This is because although we may know what measures have to be taken they may be prohibitively costly. For example, it is costing about $30 million to keep sewage effluents out of Lake Washington. How many communities can afford this amount of money, or even 10 percent of this amount? Lake Washington is fortunate in that it is in the center of Seattle, is a valuable asset to the city, and is recognized as such. I have read where one out of each six outboard motors sold in the United States is sold in Seattle. This is why Lake Washington merits such expensive treatment. Also in Lake Washington the situation is relatively simple in that the nutrients entering in the sewage effluent are in a manageable form--that is, in definite inflows that can be brought together for elimination from the lake. But this is not always the case. Many lakes are very productive without receiving sewage effluents. These are lakes such as Lake Mendota near Madison, Wisconsin, set in rich farmland with much nutrient contribution from runoff. These are lakes such as we have in the southwest part of Minnesota. What can we do about these? Well, frankly, right now there is very little we can do. We can use algicides and herbicides, but these are treatments, not solutions, and they too cost money. What I feel we must do is to step up our research program in certain directions while at the same time we must protect those bodies of water still in their unspoiled state. For example, it now looks as if Lake Tahoe on the California-Nevada Border, will be spared the fate of Lake Washington, but for a while it was in danger of becoming a victim of apathy. To use an analogy we must learn to love dandelions in fields where we cannot prevent them, while keeping on with researches to eliminate them. Also, as we are still fortunate enough to have some fields without them we must be careful not to let them become established there.

Now the researches which I have in mind are of several types. To begin with, people, and therefore sewage, are here to stay. Also it is likely that surface waters will continue to receive sewage effluents for many years. Research must be done therefore at eliminating the fertilizing nutrients from sewage. This is now feasible in the case of nitrogen and phosphorus for cities of intermediate size and will soon be so for major cities, such as Detroit, but it still is a problem in cases where treatment plants do not exist, and where treatment rests with individuals in the form of cesspools or septic tanks or small package plants. We could use studies along this line.

Secondly, we need more imaginative ways of treating already afflicted lakes or lakes that are naturally rich, rather than just poisoning the existing crop. We need long-lasting measures. We need work on ways to precipitate such elements as iron and phosphorus from lake waters and to tie up the sedimentary nutrients, especially phosphorus, in unavailable forms. We need work on the feasibility of using biological controls. An extreme example is the importation of Manatees to keep irrigation canals open. However, I am thinking in smaller terms. This summer, for example, I learned in Holland of viruses that live in blue green algae. There are also parasites that live on certain diatoms. These should be investigated to see if they can be utilized en masse. We should look for ways to turn algal production, if we must have it, toward green algae and diatoms rather than blue-greens, as the latter are the most objectionable forms and are not used as food by the small animal organisms. In this regard we also need further work on food relationships between the phytoplankton and zooplankton. We should continue studies on antibiotic relationships between algae or between rooted aquatics and algae--perhaps here we may find effective controls. These are the sorts of study I think we need to solve our problems and these are the directions I hope the Limnological Research Center will continue to take.

Prepared Statement by Samuel E. Jorgenson

The title Research on Lakes and Water-Based Recreation is very broad. So broad, in fact, that it cannot be adequately discussed in one day, nor for that matter in several days. For this reason, I will confine my remarks to Water Research and Related Research as it Relates to Fish and Wildlife. I will discuss our program--its accomplishments, its problems, and its needs.

SAMUEL E. JORGENSEN graduated with a degree in forestry, major in wildlife management, Utah State University, 1937. He was employed 1937-1940 by the U.S. Soil Conservation Service, New Mexico; from 1940-1942, by the U.S. Fish and Wildlife Service, Boise, Idaho, and Phoenix, Arizona, as a Wildlife Biologist; 1942-1945, by the Medical Department, Army of the United States; 1946-1948, as a Biologist, U.S. Fish and Wildlife Service, Albuquerque, New Mexico; 1948-1954, as a Regional Federal Aid Supervisor, U.S. Fish and Wildlife Service, Minneapolis, Minnesota; 1954-1959, as Chief, Division of Wildlife, U.S. Bureau of Sport Fisheries and Wildlife, Minneapolis; 1959-1962, as Chief, Division of Federal Aid, U.S. Bureau of Sport Fisheries and Wildlife, Washington, D.C.; 1962-1966, as Chief, Office of Foreign Activities, U.S. Bureau of Sport Fisheries and Wildlife, Washington, D.C.: and July 1966 to present, as Assistant Regional Director, U.S. Bureau of Sport Fisheries and Wildlife, Minneapolis. He was Chief, United States Delegation, First International Scientific meeting on the Polar Bear, Fairbanks, Alaska, Sept. 1965. He was a Member of U.S. Delegation to "Interamerican Specialized Conference to Deal with Problems Relating to the Conservation of the Renewable Natural Resources in the Western Hemisphere" at Mar Del Plata, Argentina, Oct. 1965.

Statistics, though somewhat boring, are useful in describing the great importance of our water resource. Every day each of us uses more than 1,300 gallons of water in one form or another. Direct use per person averages about 150 gallons daily. Industry uses 65,000 gallons of water to produce a ton of finished steel and 15,000 gallons to make an automobile. A cow drinks 11 gallons of water to produce a quart of milk, and more than 10,000 gallons are needed to grow one bushel of corn. One can go on and on with similar statistics to prove our use and need of water.

It is most fortunate that water is one of the most abundant substances in that part of our planet accessible to man. But at the same time, it is mightly scarce in some areas. Of all our natural resources, water is unique in its relationship to man. As a substance and as a resource, it is at once the means of sustaining all forms of life, a source of electrical energy, a source of food, a means of transportation, a boon to the pleasure-seeker, and too often, regrettably, a universal waste "disposal". The questions involved with water, unfortunately, are never simply ones of too much or too little, but also of how good, for what purpose, with what force, at which place, at what point in time, and at what price.

These factors in one way or another affect fish and wildlife and in so doing, they regulate the production of fish and wildlife and therefore, govern the standards of fishing and hunting. Fish and wildlife have absolute and specific requirements for water as part of their habitat needs. For ducks, water in the right volume, of the proper quality, at the needed time is critical to production of young. For salmon, many other fishes, and many game species, the generalization is the same; only the criteria differ.

We know the vital importance of water to all living things and all of our endeavors. And we know that hunting and fishing have always been one of the major recreational activities enjoyed in the United States. But do we realize just how many people, how much time, and just how much money is expended each year from the sport or recreational standpoint in the harvest of these resources? Fortunately, the new 1965 National Survey of Fishing and Hunting, conducted by our Bureau in cooperation with the several State fish and game departments, has just been completed. This National Survey covers the more significant sportsmen--those people who made three or more trips or spent $5.00 or more to fish or hunt in 1965. The Survey showed that in 1965 about 33 million persons in these categories fished or hunted, or did both. This 33 million includes 28 million persons who fished, almost 15 million who hunted, and over 9 million who did both. These same sportsmen invested over 4 billion dollars in pursuit of their sport, traveled over 31 billion miles, and spent 709 million days to hunt and fish in 1965.

Almost a fourth of the 4 billion, or one billion dollars, was spent for such items as guide fees, bait, and costs of dogs and their care. About 23 percent went for auxiliary equipment such as tents, boats, motors, and other gear for outdoor living. License purchase, mind you, amounted to only 4 percent of the total expenditures. Those agencies responsible for administration of fish and wildlife resources receive only 1/25 of what is spent to harvest the resource. I know of no business where the investment is so small in proportion to the return! Fees for entry to land and water on which to hunt and fish were a little over 2 percent of the total. This is significant since it shows that we aren't now willing to pay a very large sum for entry or trespass rights.

By way of comparison--the 4 billion dollars spent to fish and hunt is more than ten times greater than the $400 million spent by Americans for all spectator sports, including baseball, football, hockey, horse and dog racing, and other sports in the United States in 1965. One could relate comparison after comparison to denote how hunting and fishing bolsters our National economy and fits into our way of life. Suffice to say, hunting and fishing is big business! As the wise and judicial use of water is essential to good hunting and good fishing, it is apparent why we, in the field of fish and wildlife, are concerned over how our water resource is used, managed, and regrettably wasted.

I do not need to emphasize the value of research. As with other fields, research is the key to progress. So it is with fish and wildlife, and in this respect, our agency is taking a leading role. Our Bureau is very much oriented towards water since our products are products of water resources, either directly or indirectly. Further, much of our use of water is nonconsumptive use, such as that at fish hatcheries.

Through research we hope to find ways of preserving, protecting, and perpetuating our endangered wildlife species. Since the advent of European man on this continent, more than 40 species or subspecies of animals have become extinct. And now some 100 animals are threatened with extinction--but that is a story for another day.

We have hopes of developing the means of taking anadromous fish over high dams to traditional spawning grounds and returning the young safely to the oceans to complete their life cycle. We hope to increase and stabilize our waterfowl population for the enjoyment of future generations of waterfowlers. We need to erase the harmful effects of pollution in our lakes and streams to permit the growth of fish and other aquatics. Pesticides and herbicides must be brought under control. The list of problems is long, but we are responsible for their solution, and research will point the way.

The Bureau of Sport Fisheries and Wildlife divides the country into five regions for administrative purposes. This Region includes eleven midwestern states from the Dakotas and Nebraska on the west, to Ohio on the east and Missouri on the south, to Canada on the north. In this area we are responsible for fish and wildlife research and management designed to assist other Federal agencies and the State fish and game departments.

In these activities, water is a basic requirement. It is more critical to fish, waterfowl, and certain aquatic fur animals than to upland game species. Nevertheless, its availability in the proper quality is essential to all.

In the midwest area, we administer 20 National Fish Hatcheries and 63 National Wildlife Refuges. Management services for both fish and wildlife are provided on military reservations, Indian lands, veterans hospitals, and other Federal installations. We administer a large Comprehensive grant-in-aid program with the States for fish and wildlife restoration. We study Federal water control projects, dams, reservoirs, navigation projects, diversions, etc., and recommend measures to mitigate or enhance fish and wildlife resources. We enforce Federal laws relating to wildlife. Our Divisions of Wildlife Research and Fishery Research are doing considerable fundamental or basic research.

As you know, some of the most important waterfowl production habitat in the conterminous states is in the upper midwest. To further preserve this dwindling habitat, 1,750,000 acres of wetlands are being acquired in the prairie pothole region of the Dakotas and Minnesota. Research brought forth the facts on which this acquisition program is based.

In wetlands, we have vast opportunities for research, both pure and applied a new field which has scarcely been touched upon, not through any lack of interest but because of lack of funds heretofore. By nature, our marshes and estuaries are the frontier between the two great ecosystems of land and sea--the area in which the controlling forces of each combine to produce a whole new range of conditions. No two marshes are quite the same. Everywhere there are gradients of salinity, temperature, depth, and current; differences in geological formation and topography; degrees of alkalinity, and many other factors interacting to produce almost endless variations.

And all these factors somehow are related to waterfowl production and waterfowl use. Why does one marsh attract waterfowl while another marsh, seemingly identical, is not used. We must find the answer to such problems. We must learn how to produce two or perhaps four ducks where only one was produced before. Public interest suggests that marshes should be kept as waterfowl habitat. Private interests seek to convert wetlands to other uses for immediate economic gain. The problems of marsh conservation are social, economic, and biological. There is social need for wildlife produced on marshes, an economic need to gain the highest possible return from wetlands, and a biological need to find ways to serve these two needs at the same time through increased wildlife production and use of marshes.

To this end, we have recently established the Northern Prairie Wildlife Research Center at Jamestown, North Dakota. In cooperation with the U.S. Geological Survey, this unit will study factors affecting the permanency of prairie potholes as related to waterfowl use. It will study wetland ecology and the factors affecting quality and permanency of water in small wetland areas of waterfowl breeding habitat. This will involve intensive work on hydrological, physical, chemical and biological characteristics of wetland habitat. Long and short-term objectives are underway. Time is of the essence--let us hope that we are not too late. The continued dwindling of our waterfowl habitat and numbers must be curbed.

Fishery research is equally paramount. Across our country, we have 17 fishery researeh stations which are engaged in long-term fundamental research. Activities are varied and far reaching. For example, our laboratory at Buelah, Wyoming, works on fish genetics; Stuttgart, Arkansas, deals with experimental fish farming in connection with rice culture. Exotic fishes are included in these studies. Our internationally known laboratory at Cortland, New York, has made major contributions in fish nutrition. Today we convert 1.9 pounds of food to 1 pound of trout. This respresents a tremendous saving. The effects of pesticides on fish are being researched at Denver; this work soon will be transferred to a new station in Columbia, Missouri. Reservoir research is underway on the Great Lakes of the Plains in South Dakota and in Arkansas. A "salmon-cultural" laboratory is in operation at Longview, Washington, and a fish disease laboratory is hard at work in Seattle. Other stations are doing equally important work in the field of fisheries research.

New to this area is our Fish Control Laboratory established in 1959 at LaCrosse, Wisconsin. The mission of this unit is the development of means for control or manipulation of freshwater fish populations. In particular, safe and economic controls--chemical, biological, electrical, or mechanical--are sought for controlling undesirable or unwanted species of fish. The objectives are sufficiently broad to encompass investigation and development of any new tools that may be useful in fishery management, fish culture, or fishery research.

Early recognition was given to the potentials of chemical control agents. The chemistry and physiology laboratories are concerned with general and selective toxicants, attractants, repellents, anesthetics, sterilants, spawning inducers, osmoregulators, marking dyes, medication for diseases, sedatives, and decontaminants for fish distribution. Emphasis is one finding selective toxicants for longnose and shortnose gars, gizzard shad, goldfish, carp, squawfishes, white suckers, bullhead, rock bass, green sunfish, pumpkinseed, yellow perch, and freshwater drum. At times these fishes are serious deterrents to production of more desirable fish. Many chemicals have been tested; nearly 1/2 million fish of 34 species are used annually in the screening program. Results are very encouraging, but we must not forget that this is a new science that will require time for accomplishments. We must also remember that our sister agency, the Bureau of Commercial Fisheries, did the almost impossible by finding a specific chemical control for the dreaded sea lamprey that depleted the lake trout from our Great Lakes waters. This chemical is introduced to streams after the young of the lamprey have hatched.

I would like to discuss now some of the results of short-term or applied research which is being conducted at some of our field stations. Our McNenny National Fish Hatchery at Spearfish, South Dakota, is a Diet Testing Development Center for trout. It provides full-tested, open-diet formulas for use in Federal, State, and private hatcheries. Many hatcheries in other regions are now using diets developed by this station. The Jordan River National Fish Hatchery in Michigan is engaged in a program to evaluate the success of lake trout stocking in Lake

Michigan. The young fish are marked by fin clipping. Investigations of rearing channel catfish in raceways continue at the Senecaville Hatchery in Ohio. We are conducting a few long-term projects that include the evaluation of ultraviolet sterilization of water supplies, work on fish egg disinfectants, antibiotic therapy, and air spawning techniques; and many other projects with far-reaching consequence are on the drawing boards.

One of the newest and most vital segments of our fisheries program is directed to training of fishery workers at Cooperative Fishery Units. Each unit is a cooperative venture involving our Bureau, a college or university, and usually a State game and fish department. Of the 23 authorized Units, four are in the Midwest--Iowa State University, Ohio State University, South Dakota State University, and the University of Missouri. Research by Unit personnel and by graduate students is a major objective of the program. These projects are primarily directed toward solution of ecological and environmental problems and development and evaluation of techniques. They are attuned to management needs to provide maximum public recreational enjoyment. The Units provide training at the graduate level and support a wide variety of field and laboratory studies relating to fish.

For instance, the program of the South Dakota Fishery Cooperative unit enhances research in the following areas: physical, chemical, and biological characteristics of shallow lakes, typical of the region; fish population dynamics in lakes and small impoundments; species manipulation and establishment of game fish populations in small streams and impoundments not used at the present time; and effects of agricultural, domestic, and mining pollution on the sport fishery of South Dakota. The Missouri Unit research program is concentrated on warm-water fish production and population dynamics. Studies are aimed at an understanding of ecological and physiological factors influencing growth and survival of fishes, with the principal objective of understanding and managing the dynamics of fish production. The limnology and ecology of acid waters in strip mine areas are receiving attention. There are many other individual projects underway to solve problems confronting the fishery management biologist.

Our wildlife men are similarly involved in short-term research at our refuges. We have long used applied research in our goal to perpetuate and, where possible, enhance waterfowl populations. The great strides made in Canada goose management are reflected in today's game regulations and seasons. We are now studying methods to create and improve waterfowl habitat through food and cover developments, water level manipulation, and noxious weed control. Research on habitat requirements, ecological relationships, migratory habits, and population dynamics of important waterfowl species is continuing at an accelerated pace. Surveys and inventory techniques and the effects of various hunting regulations on the kill levels are being developed to a high degree of accuracy. Agricultural studies underway will be invaluable in the eventual propagation of the whooping crane and other rare and endangered species. These are only a small part of our research program. One cannot forget that pesticide-wildlife relationships, disease and parasite control, lead poisoning, and botulism are just a few of the mysteries that must be solved in the not too distant future.

We are now entering into a new field of endeavor--a field in which this panel is greatly interested. Daily, we are being made aware of the devastating effects of uncontrolled use of herbicides and insecticides and pollution on fish and wildlife. Many millions of dollars are to be allocated by the Congress to clean up our rivers, lakes and streams. Laws are being passed to tighten control over the use of plant and animal toxicants. The problem has been editorialized in every major newspaper and periodical in the country, and it has become a by-line of the Administration.

For some time we have been involved in pollution investigation studies in the Great Lakes Basin-Illinois River. These are sponsored by the Federal Water Pollution Control Administration, and we are one of several cooperating agencies. Soon we will become involved in similar studies on the Red River of the North, Souris River, Rainy River, and the Missouri River basins. Before long, every major river system in our land will be the subject of a pollution study. So far, our work has been of a preliminary nature concerning case histories and current trouble spots. Reporting efforts have been given broad coverage and our recommendations have been of a general nature.

These studies will formalize a plan of attack, and it will be up to research to put forth solutions. To date, acceptable water quality standards for fish and wildlife have not been established in many areas. We welcome the challenge and opportunities that these research and study programs bring to us.

Prepared Statement by Robert C. Lucas

Jerome Kuehn divided research needs into two categories: research on resources and research on recreational use or activities. This is a legitimate division, although as he notes, the two parts are closely

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connected. I will also use it. I will concentrate my remarks on the second category--research needs related to recreationists and their activities.

I agree generally with Jerome Kuehn's statements about the reasons for the shortage of research on recreation--lack of respectability, recent awareness of a problem, difficulty (I would say "apparent difficulty" because I think unfamiliarity makes the difficulty look greater than it is), and lack of data. You might add lack of financial support. There is improvement, however, on all of these fronts.

Within the category of research on users and activities, three specific needs for improved water resource management for recreation stand out in my view. These three fit into some of Jerome Kuehn's thorough list of topics and overlap others. They are implied in his analysis, but I think they may deserve additional emphasis.

First, is the study of outdoor recreation resource use as related to changing perception of changing resources and opportunities. This involves both the study of land use and activity patterns over time, and a human decision-making. A number of studies have shown great variation in the use of recreation resources from place to place--the question is what factors underlie this variation?

I can give two examples of this sort of research from our work at the North Central Forest Experiment Station. First is a study of lakeshore home land use in Crow Wing County (the Brainerd area) by George Orning. Crow Wing has more lakeshore homes than any other Minnesota county, and probably is an indicator of future trends elsewhere. The relationships between degree of development on the one hand and lake characteristics, resource combinations on lakeshore lots, and road access for the 1960 pattern on the other hand have been analyzed. Lake size, shoreline soil material, presence of aquatic vegetation, and size and type of forest cover proved significantly related to degree of development; access and a number of other variables did not. There appears to be resource capacity in Crow Wing County for a tripling of a number of cabins (under assumptions I must skip here) but the most desirable resource combination is nearly saturated already.

Study of the 1920, '30, '40, and '50 patterns will show how stable these relationships have been.

This study exemplifies the interconnection of research on physical resources and on resource use. Before the cabin development pattern could be related to resources, resources had to be described. This was a big job; data were assembled from the Minnesota Conservation Department, soil surveys, highway maps, and aerial photo interpretation, and punched onto one electronic data card for each government lot or 40 on a lake. Now it is done, and the information could be used to help guide such things as acquisition of northern pike spawning areas, county zoning, and so on.

The second example of basic process studies is one I am doing of factors related to the distribution of recreational use on two National

Forests in Michigan. It appears, for this area, that about five already inventoried resource variables account for about 70 percent of the variation in campground use as a percent of capacity. A dozen or so other factors proved minor. Resource quality evaluations by visitors differed considerably from evaluations previously made by professional resource planners. Visitors rated beaches higher, fishing lower, and water for boating quite differently. As a result, rankings of sites based on the sites' combinations of resources would probably differ widely between visitors and managers.

This general type of research, as it is developed and strengthened, should enable resource managers to predict more accurately the public response to different management alternatives.

A second major topic needing study is the determinants of demand. Topic one dealt with the effect of resource character and location on recreational use; two deals with the effect of income, education, leisure, residential environment, and other factors on recreational participation.

The repetition of the standard mobility-income-leisure-population "explanation" is not enough. We need studies in depth of specific activities with specific resource requirements. We need true studies of demand as a variable response to price, or other factors, rather than consumption misnamed demand. These studies should include time series data. A small start was made in this sort of research by the Outdoor Recreation Resources Review Commission (ORRRC), but their study was based on one cross section in time, and for rather broad categories of activity. Their results do not apply to individual States--their sample was not large enough. Furthermore, they were not able to account for very much of the variability in participation. David A. King, while on our staff, investigated camping demand as related to social and economic characteristics on two National Forests--and he found most of the variability in amount of camping unexplained also. There was a stronger relationship, however, between the factors studied and whether a family camped at all.

We do not know much about how preferences form and develop, or how opportunity (or supply) interacts with preference. As a result, we have no basis for predicting how desires are likely to change in the future. And preferences, tastes, and so on are almost certain to change; most major types of outdoor recreation are quite recent as widespread activities. Waterskiing has less than a 20-year history, snowmobiling not much over 5 years. To assume that present preferences will be stable to 2000 A.D. seems very risky.

If resource planning is to be at all long range, better use projections are essential. Without much better understanding of demand relationships, projections cannot be accurate enough to be useful.

Research on demand, as defined here is increasing. It is interesting that one recent study based on demand analysis concluded that

ORRRC's projections were low, unless crowding stops growth.[1/]

The third topic is closely related to the first two. It is the question of recreational quality and what influences quality. This is a part of several of Jerome Kuehn's topics--carrying capacity and resource evaluation, especially, and it has a crucial bearing on several others--resource allocation and pricing in particular.

Ways of objectively measuring quality are needed badly. As long as we can only count people, but cannot assign any sort of index of quality or value to the activity, there is a bias towards more intensive uses (or mass recreation) in planning decisions yet we are reasonably sure that some types of recreation are subject to diminishing quality with increasing intensity, at least beyond some point.

There are really two questions here. First, how sensitive is the quality of a given type of recreation, say fishing, to variation in related variables--such as species of fish, number caught, size of fish, water quality, shoreline vegetation, character of adjacent buildings, numbers and types of other recreationists, and so forth. Answers to this question are needed to develop standards for water recreation. The other question involves value comparisons between types of activities where a decision as to "the highest and best use" must be made. For example, how does a day of a specific quality of walleye fishing on a wilderness lake compare with identical fishing on the same lake if roads, resorts, and cabins were built around it? This is a very difficult question--maybe it cannot be answered objectively--but resource allocation depends on some kind of answer.

Even partial answers to these three interrelated questions would go far to improve our planning and management of recreational resources, among which water is so important. If planners could better predict recreationists' use of particular resources managed in specific ways, better project future general desires or demands, and knew how the quality of resource use responded to variations in the opportunities and resources provided, planning goals could be much better achieved.

Minnesota has great resource potential. It has a higher proportion of area in lakes and streams than any other State, except some coastal states where largely enclosed ocean bays are counted, and it has the major wilderness lake area each of the Rockies. The best planning possible for the recreational use of these water resources will contribute importantly to the quality of life for the people who live here. In addition, improved planning is almost certain to benefit many recreation-related economic activities and some low income regions. It can also increase the attractiveness of Minnesota's somewhat marginal location relative

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1/ Wayne E. Boyet and George S. Tolley, "Recreation Demand Projection Based on Demand Analysis," Journal of Farm Economics 48(1):984-1001 (Nov. 1966).

to the major market areas of the U.S., especially for many of the kinds of rapidly growing "scientific" industries that most people would consider most desirable. The importance of attractive open space as an economic location factor has already been demonstrated by the Upper Midwest Economic Study.2/ In summary, the possible rewards to better planning based on improved research seem worth an increased effort.

2/ John R. Borchert and Russell B. Adams, Projected Urban Growth in the Upper Midwest: 1960-1975, Urban Report 8, Upper Midwest Economic Study, 1964.

RESEARCH ON SOCIAL-ECONOMIC ASPECTS

Principal Paper by Raymond A. Haik

This discussion of the need for research on the social and economic aspects of water resource management coincides with the requests submitted by large cities to the Congress of the United States for assistance to aid them in solving the social and environmental problems of our core cities. These requests are based upon the recognition that the allocation and use of resources must of necessity deal with the demands and desires of human beings. Today's challenge for our public officials is the preservation of the quality of our total environment; thus, any discussion of water resource research must involve all other resource users that are affected by or have an effect upon the quality of our environment as well as the water resource specifically.

Other papers, in reviewing the needs for research on the physical aspects of water, have demonstrated that any attempt to label the research needs of one county, of one state, or of one nation as being similar to other counties, states, or nations, is to ignore the obvious fact that water and its availability varies greatly throughout the nation and, in fact, throughout Minnesota. While one state or county may be struggling with the problems of managing an inadequate water supply, another may be faced with managing an overabundance of water and the necessity for flood control measures. These physical differences require a qualification that water should not be studied without regard to other resources, nor should we become overly protective of present uses. We must be concerned with the changes in water use resulting from human preferences, and we must develop a means by which there can be a flexibility in our water rights to meet future water use needs. An immediate problem of allocating water resource use results from the lack of a legal framework to evaluate and protect water quality for which I consider to be the subjective aesthetic uses associated with recreation, wildlife and open spaces.

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If we consider law as merely a tool to resolve conflicts as to the use and management of water, we can leave the decisions that involve these aesthetic, subjective uses to be settled in the normal course of events by a court or administrative agency. The public will probably not be satisfied with the present process and they will demand protection of the natural environment.

There is a growing awareness by the general public of the need for water quality and at the same time, there is a growing demand that regulations be imposed which will correct the results on water quality of long neglect and abuse of our major waterways. In responding to these demands, we must be careful not to leap at the obvious, which may be more government regulations.

As other speakers have indicated, a fraction of the total amount spent in water resource development in the United States has been allocated to research. Oftentimes, many years after a water project is completed, effects occur which were not anticipated and at time are more important than the water effects for which the project was designed. These effects require that water management plans must consider all scientific knowledge available, as well as the social impact of a particular water project. The social and political implications of water resource management programs must be better understood.

The research topics discussed earlier illustrate better than any lengthy discussion that our water resource can no longer be considered in relation to a particular dominant use without the advice of the social and political scientist whose assistance is oftentimes the key to the implementation of a water management program dictated by our physical knowledge of water resources. Other speakers have discussed the hydrologic cycle, the sources of water supply and distribution in the United States as well as the demand made upon water resources. I have had an opportunity to visit some of the nation's major waterways and to see firsthand the data collection systems and other studies of the physical aspects of water; however, the management plan which may result from such studies will just be gathering dust on a shelf unless there is developed, at the same time, an institution which can carry out the particular management plan.

In considering needed areas of social research, I believe we should recognize that one of the most difficult problems is the measurement and evaluation of those uses which are subjective in character, and oftentimes are not given a dollar value. These are the uses of water for outdoor recreation, aesthetic, and wildlife purposes.

If we consider the metropolitan Twin City area of St. Paul and Minneapolis in relation to the population and area of the entire state, we must conclude that this area is a vital factor in the economic well-being of the State and its citizens. Assume that we are able to plan the development of the Twin City metropolitan area to handle today's population of approximately 1,800,000 and the projected population of 4,000,000. In formulating the plan for absorbing this population, as

well as the industries and land and water use practices that result from such a population, I believe that we would all recognize that we must provide for those water uses which are not easily assigned a dollar value under today's economic considerations. By these, I mean the aesthetic and recreational uses of water. These uses are extremely important, as they affect the quality of the total environment for the 1,800,000 and eventually 4,000,000 residents of this metropolitan area. Certainly we could not expect that these people would live in an environment where the water use was devoted strictly to utilitarian purposes for industrial and human needs. Of necessity, there would be segments of the water areas used for aesthetic, wildlife, and recreational purposes, if for no other reason than the fact that these uses are necessary and considered advantageous to the social and personal needs of the population. The problem is how these uses are to be valued and preserved.

In a society such as ours, we traditionally have looked to the political sciences for the development of the institutional forms which are needed to resolve conflicts as to water use. Given the problem of allocating a limited water supply, the political scientist would be required to value the several demands made upon the water resource. An illustration of such conflicts would be whether it is advantageous to allow the maximum development of land, and the use of water that would result in the impairment of water quality in the Mississippi River downstream of the metropolitan area. If it were the value consensus that we preserve natural and scenic areas highly suited for aesthetic and recreational purposes, the political and social scientist would be required to develop the institutional forms by which such a political decision could be made so that the water quality in such areas would be preserved at the highest level possible.

If we determine that aesthetic and recreational water use is extremely important to the environmental climate in which the 4,000,000 population will live, we must also involve the social scientist in our research programs. It would be the duty of the economist and political and social scientist to present to the general public for their decision, the alternatives and costs involved in obtaining a certain desired water quality standard. When such a consensus has been reached, then ideally the political scientist would be able, through the legislative body, to develop an institutional governmental form which could carry out the public consensus as to the appropriate management plan for water resource use in the Twin City area.

To the extent that we presently have a means of reaching a public consensus, it has developed through a legal process that assumes that every water use can be carried out on every waterway within the State. This, in essence, underlies the riparian doctrine of reasonable use as followed in Minnesota. This doctrine implies, contrary to the fact, that the owner of land along the watercourse has a right to receive the water at his property undiminished in quantity and unimpaired in quality. Under the reasonable use theory, this riparian owner has the right to make a reasonable use of the water subject to the equal right of the owners above and below him to use the water for similar purposes. A prior water user does not secure rights over a non-user, and a right to use water is not created by use or loss by non-use. What constitutes a reasonable use depends upon the facts of the particular situation, and the resolution of such conflicts has generally been left to the corts or the administrative agencies. In practice, the segments of society which had a present need for water have met their demands either through legislation or through the exercise of their riparian right to make a reasonable use of water. The result is a situation where a downstream owner's use for many purposes is destroyed by the multiplication of many other upstream uses over which he has little, if any, control. His legal remedy is often of little use.

Implicit in our past approach to water resource management has been the assumption that the determination of the social and economic values involved in a good water management plan is best made by a state agency empowered to control all water use, or by a court deciding a specific case of reasonable use. This reliance on agency control has been evident by the establishment of governmental jurisdictions, whether they be federal river basin agencies such as the Tennessee Valley Authority or the Missouri River Development, or proposed interagency river basins and commissions such as the Delaware River Basin Commission. There is need to evaluate such an approach, because of the fact that only an agency with considerable authority can effectively implement a water management plan that covers many states and the hundreds of municipalities within the several states. At the same time that there is a recognition of this need for authority to implement a management plan, there is also a recognition that the forum for determining the social and economic issures with respect to the cost of a particular management plan is best left with the public and local communities, who oftentimes are most acquainted with the subjective, environmental needs of their area. Too often, the result has been that while we are waiting for the creation of a comprehensive institutional system to manage all water resource use, we are not doing the things that can be done in the smaller areas to more intelligently manage water use.

While we must not reject the river basin approach with a large system of federal waterways under one plan of management, we must make the same effort to delineate the appropriate sub-management unit which can determine the social and economic values that should be considered in allocating future water use. One can argue that the states have lost some of the momentum, and as a result some of their authority to control water use, by reason of inaction, but it would appear that the final solution as to the best governmental agency will depend upon experimentation and the effort made to develop a public consensus. The states would be wise not to delay action in solving water management problems in their heavily developed, smaller and medium-sized sub-basins while waiting for agreement on the appropriate interstate and federal-state institutional form for the larger management area.

At the same time that there is the reliance on the eventual creation of a strong water agency at the state level and the need for a federal

waterway management plan comprising the areas of several states, there is also need for a study of the economics in the use of water and the allocation of a limited water supply to portions of a state or to one state our of several in a particular basin. While we are discussing the need for the governmental institutions required to manage water use and resolve differences as between various water users, it is important that in our desire for centralized planning and management of resources, that we do not ignore the private sector of the economy and the need for revisions in our water laws which will result in a water right that can be readily assigned or sold to a water user needing an additional amount of water. There may be many areas where the use of water and the regulation of water supply could be easily handled by allowing the sale or purchase of the water right.

The need for a better understanding of the possibility of development of private property rights and the use of the market system and the allocation of water resources is discussed in a book entitled Water Supply Economics, Technology and Policy a publication of the University of Chicago Press. As the authors point out, one of the reasons for the acceptance of the fact that the allocation of water rights is best decided by a strong governmental agency having full powers, is the statement that such regulation is needed because the water resource is different from other natural resources.

As the authors discuss, such a concept has often resulted in uneconomic use of our water resources, and the initiation and development of large federal and state water projects. Although state participation in water resource projects has been quite small in relation to the federal projects, the state governments have influenced decision-making and water use management through retention of restrictions on the transfer of water rights by property owners. This has meant that the debate and conflicts between competing water users is resolved in the State Legislature or the courts, wholly apart from the context of the total need for an integrated water management system that recognizes social, aesthetic and wildlife uses of water. Such uses are not easily assigned a dollar amount, and their protection too often is left to the conservationists or other public interest groups.

As a result, the particular water user makes use of the water and awaits a challenge to his use, with the eventual determination as to what constitutes a reasonable use left to the court. Such a concept of reasonable use within the framework of an economic system where water rights would be transferred prevents the easy transfer of a water right, assuming it were legally possible, because the prospective purchaser would be hesitant to pay any large sums of money for a water right that was based upon an unknown reasonable use determination. The lack of quantitative amount of water causes many uncertainties to a prospective purchaser, and the so-called water right as a real property concept loses much of its meaning. The end result is that the exchange or transfer of water rights between competing users and uses by the market process of sale is severly hampered. There has not been too great a hindrance to the allocation of water by application of the reasonable use riparian doctrine because of the fact that we have not yet reached the time when there is a variety of conflicting demands upon a limited water resource. As demand for water increases, the question of the economic and efficient allocation of water resourses will become more important, and the inefficiency of the judicial decision-making and governmental process will become more acute.

The following topics for social and economic research could be considered.

A study of the character of aesthetic and recreational opportunities in large metropolitan areas, and an evaluation of how such uses might be affected by use of water for waste disposal and other utilitarian purposes. Maintaining aesthetic, recreational and wildlife water qualtiy in close proximity to the large metropolitan areas will become more costly as the demands to use the water for industrial purposes or dilution of public wastes increase in direct proportion to the population.

Any multi-purpose resource development involves difficult and subjective decisions as to the value of use in terms of dollars. Study of all aspects of aesthetics, recreation and public health, as it may involve water quality, must be considered. Consideration should be given to the development of a procedure for ascertaining the consensus of the public, including opportunities to evaluate the cost of a particular management plan. Existing political and institutional processes must be evaluated in terms of the adequacy of the public representation.

Study of the water laws to determine whether they effectively establish a water right capable of economic treatment with respect to valuation, transfer and sale in the same manner as other mineral resources. Such a study could consider the manner in which aesthetic and recreational water uses would be preserved if water rights were allowed to become secure without limitation on transferability. Would the economic market process allocate water resources to their most productive use, if the test is the amount that a water user would pay for a water right? Should the public use be acquired by exercise of the power of eminent domain?

If a market were allowed in water rights in the same way as in other resources, would uses of water be subject to better scrutiny prior to undertaking expensive water projects.

A study of the economic considerations involved in the so-called 'spillover' effects on the use of water. Such a study could result in legislation restricting stream pollution or restricting appropriation from upstream locations because of the deterioration in water quality in downstream areas.

An evaluation of whether the most efficient and economic allocation of our water resource will result from the establishment of the governmental agency having unlimited authority and control over water use.

A study and evaluation of the extent to which existing statutes and court law impair the effective transfer and allocation of a water right among private water users. Such a study would include analysis of whether existing studies and court decisions create uncertainty as to the water right and reduce the incentive to develop and invest in a water resource management program. An example of this would be the reasons for the change sought by the mining industry prior to the investment in the taconite benefication plants of northern Minnesota.

An examination of the extent to which leaving the allocation of water resources to the market process would result in the waste or nonuse by an owner of a particular water right.

Study could be given to the advantages and desirability of allowing the transfer of property rights in water from one use to another, and from one place to another. Such a study would include the legal basis for restrictions imposed upon the use of water by property owners, and restrictions that would prevent the transfer of a water right to adjacent lands or lands in another watershed basin.

Study would be given to the problems involved in allocating priority of use to a particular water use, and the result of such an allocation upon the transferability of a water right as the demands and desires for water use change.

As a member of the Governor's Committee on Water Resources, I was immediately impressed with the almost unanimous conclusion that the best way to manage water resource use was by the establishment of a strong state water agency. For purposes of this presentation with respect to research needs on the social and economic aspects of water, I would only raise a question as to whether we have adequately explored the alternative to a strong, centralized government agency to allocate our water resources. The alternative to such an approach could be the decentralization of the decision-making process with respect to the use of water by allocating and allowing the market and private property concept of water use to play a role in the development of a water management program. It may be that it would be desirable to increase the scope of individual decision making in the allocation of water resources. More consideration of the economics might get to the heart of large government water projects which are often criticized as not being economical, particularly programs of the Bureau of Reclamation which seek to increase agricultural production artifically in arid sections of the nation. Such an approach might also tend to evaluate the need for large hydroelectric power systems as part of the multi-purpose federal water projects if their principal purpose is to obtain the revenues needed for financing the more costly irrigation aspects of the project. The same study should consider methods of allocation of the cost in complex multi-purpose water projects. There is need for increasing participation by beneficiaries in the payment of the project costs.

In my paper, I have quickly touched on several research needs but there is one which should be in all our minds. That is the need for a procedure which will offer the general public a change to evaluate alternative courses of water use. Too often, aesthetic and recreational uses are lost because the water use decision is made without the public being aware of the range of choice as to the cost of the alternatives, as well as the effect on the environment of the area. Frequently there is observed a tendency to overemphasize the separation of public from private decision-making in the consideration of water resource management problems. Actually, there is a great deal of intermingling of public and private interest influence and effect.

It is hoped that this matter will stimulate some discussion of the social and economic questions concerning the future of water management programs to be followed within Minnesota, especially if there is any indication that the conclusion has been reached that we can only manage our water resources by creation of a strong, centralized, all-powerful agency of government.

Prepared Statement by Raymond D. Vlasin

In this paper on "Social and Political Research as Part of a Water Resource Management Program," Raymond Haik does two things. He gives us some useful observations he has made in his several capacities in water resources work. Then he touches on a number of possible topics for economic and other social science research that could be considered in Minnesota.

In reacting to Raymond Haik's paper, I will make some comments about his observations and about the topics he enumerates for research. Then, I will raise some specific questions for his consideration and reaction.

Raymond Haik's observations in the first portion of his paper range broadly. However, common to his observations appear to be five major

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points. One is concern for the quality of the environment. A second is determination of possible uses and values of water for recreation and aesthetic purposes in that environment. A third is development of an organizational form to implement and protect water use for recreation and aesthetic purposes. A fourth is improvement in water rights and in their transferability in the market place. A fifth is caution against creation of a strong, centralized all-powerful agency of government for administration of water use. And, a sixth is the suggested role of the social scientist and social science research in the above areas. Raymond Haik makes a number of specific observations related to these six points. Some deserve additional emphasis.

I agree that one of the real challenges for public officials is preserving the quality of our total environment. I am quite sure Ray mond Haik means to include within this challenge improving the quality of those portions of the environment that we have seriously polluted to date.

The Report of the Environmental Pollution Panel of the President's Science Advisory Committee points out in clear terms the combined enormity of municipal and industrial sewage, urban solid wastes, consumer goods wastes, animal wastes, mining wastes, soil pollutants, and other wastes or pollutants we release into our environment daily.1/

For example, municipal and industrial sewage dishcarges alone in the United States correspond to the raw sewage from almost 50 million people. These wastes and large portions of others have been finding their way into our water resources for some time. I doubt whether many of us fully grasp the pervasiveness and magnitudes of pollution. Mr. Jorgensen's comments about the pesticide residues found in the bodies of penguins and seals in the Antartic and about polar deposits presumed to be from automotive exhausts give a hint of how pervasive pollution.2/

The newly enacted Federal Clean Waters Restoration Act of 1966 will surely help. This new anti-pollution law is expected to make available more than $3.5 billion to states for water conservation projects by fiscal 1971. Minnesota's share could be as much as $66 million in federal grants.3/

1/ Restoring the Quality of Our Environment. Report of the Environmental Pollution Panel, President's Science Advisory Committee. The White House, November 1965. For a discussion of sources of pollution and their magnitudes, see pages 10-12. For recommendations on physical research to restore the quality of the environment, see pages 29-33.

2/ S. E. Jorgensen, Discussion of Research on Lakes and Water-Based Recreation. Conference on Water Resources Research Needs in Minnesota. St. Paul, November 15, 1966.

3/ See, for example, quotations from Lyle H. Smith, Water Pollution Control Commission, published in Minneapolis Tribune, "New Law Will Boost Anti-pollution Aid". November 12, 1966, page 9, columns 2-4.

However, the combined task of raising state and local matching funds for sewage treatment and construction of municipalities and sewage districts, and the task of handling pollution from other than raw sewage sources will be enormous.

Raymond Haik stresses than an immediate problem of allocating water resource use results from the lack of a legal framework to evaluate and protect water quality for the aesthetic uses associated with recreation, wildlife, and open space. I believe he would agree that we have components of such a framework.

The Minnesota Water Pollution Control Commission with its laws and administrative procedures is part of such a framework. Also, we have the Federal Water Quality Act of 1965, under which Minnesota plans to enact standards for interstate waters or portions of them within the State. Public hearings are being held as one step in developing and adopting water quality criteria and a plan for implementation by June 30, 1967. The criteria and plan will be reviewed by the Secretary of the Interior for adequacy and for consistency with the purposes of the Act. If his determination is favorable, Minnesota's criteria and plan will be adopted and used in enforcement of federal water pollution control legislation. One of the real challenges will be whether we can use these two components and others to develop an integrated framework of quality protection on interstate and state waters. I recommend that Minnesota vigorously pursue this possibility.

Raymond Haik is correct when he states that the economist and other social scientists should show the alternatives and costs involved in obtaining a desired water quality standard. He is correct also when he points out that the social scientist can be most useful in devising an organizational form for implementing a particular plan. However, we have not used our social scientists fully if we merely call them in to figure out what plan A or plan B will cost or how to implement plan A or plan B once these plans are chosen.

Given both time and resources, the social scientist can point out alternative developmental opportunities others may not have anticipated or articulated. Likewise, the social scientist can point out resource-use or developmental opportunities that might be lost temporarily or permanently by proceeding with a particular course of action. These latter roles are particularly significant since they serve to expand the choices considered in resource use and to improve the factual basis for deciding among those choices.

For example, we are not interested in water quality as an end in itself. Rather, we are interested in its contribution to maintenance of human health, fish and wildlife development, recreational development, urban development, agricultural development, other forms of industrial development, or some combination of these to improve the welfare of people. Identifying and clarifying choices among these various objectives are most important for improved decision making and, they are functions upon which economists and other social scientists thrive.

If social scientists are to serve effectively and fully in pointing out possible developmental opportunities or choices and their consequences, they must be involved in the physical research or evaluations that underpin the decisions. They must be full partners from the start. Further, they must have adequate research support.

Raymond Haik suggests a number of research studies for consideration. They all have merit. Time permits me to comment only on a few.

He suggests a comprehensive study of water laws to determine whether they effectively establish a water right capable of economic transfer in a manner similar to mineral rights. Raymond Haik also suggests companion studies on current legal impairments to transfer and allocation of water rights among private users, and on the effects that allocating water rights in the market place would have on waste and nonuse of water.

Minnesota water law now permits some economic transfer.4/ Greater marketability of water rights does not automatically insure a better situation for all. For example, the externalities or spill-over effects associated with water use are very numerous. The market place does not provide a way for penalizing those whose use has adverse external effects on others nor does it have a way of rewarding those whose use has beneficial external effects on others. If studies on increasing marketability of water rights are undertaken, I hope they are broadened to include consideration of externalities as well as possible effects on the public cost of providing water for public use.5/

Raymond Haik suggests a study to determine whether the most efficient and economic allocation of water resources will result from the establishment of a governmental agency having unlimited authority and control over water use. I am not sure what an agency having unlimited authority and control over water use is, or whether it could exist. I suspect Raymond Haik means the evaluation of a possible agency with substantial centralized authority such as created under Wisconsin's new water law.6/

4/ Harold H. Ellis, "Water Law in Eastern United States." Journal of Soil and Water Conservation, Vol. 18, No. 1. January-February, 1963, pages 19-27.

5/ Another possible study that deserves attention is the evaluation of the present acre-feet limitation, usually the equivalent of 6-inches per acre. There is serious question whether the 6-inches per acre limitation is adequate for all areas of Minnesota or for all agricultural users. This has particular relevance for possible future developments in irrigated agriculture within Minnesota. For a discussion of these points see C. Nohre and P. M. Raup, Regulation of Water Use in Agriculture. Minnesota Agricultural Experiment Station Bulletin 453. March 1961, pages 19-20.

6/ Wisconsin Laws of 1965. Chapter 614.

The new Wisconsin law is designed to grant necessary powers to organize a comprehensive water program under a single state agency for the enhancement of the quality management and protection of all waters of the state. It will encompass ground and surface waters, and public and private waters. Research associates of mine at the University of Wisconsin indicate the new law embodies a substantial advancement in legal and organizational tools for water resource management and development.

Raymond Haik also indicates that we have not explored adequately decentralization of the decision-making process in water management as an alternative to a strong centralized government agency. I agree. But, let's recognize that you can't decentralize until lower units of government are willing and able to hire necessary new staff. As you go below the state level, staffing problems increase substantially

Two other points can be made regarding decentralization. First, we don't know what governmental functions and services, including water management activities, can most efficiently be handled by the different levels of government. We badly need research results on the economies of scale for the various water management activities and other services and functions. Also, we don't understand the role of single- and multiple-purpose resource districts in water development and management. Research at the Minnesota Agricultural Experiment Station7/ and elsewhere has shown the need for economic research on the organizational and operational aspects of the various single-purpose and multi-purpose resource districts. The Experiment Station has initiated such a study in cooperation with the Economic Research Service of the U.S.D.A.

In addition, I would like to stress the need for more systematic research attention to the possible integration of water planning efforts with other resources, community, and regional planning efforts. I am particularly pleased that the State Planning Agency is now underway. It may serve as a catalyst to provide added linkage and complementarity among those involved in river basin planning, regional planning, statewide resource planning, watershed planning, planning for multi-county and smaller development districts involving water, county-wide comprehensive planning, municipal planning, and still others. Inter-governmental cooperation on water management and other functions is indeed one of the growing challenges for the future. Research can help.

I would like to recommend additional inquiries in view of the hearings being held to develop water quality criteria for use on Minnesota's portion of interstate waters. As a top-priority item, I would recommend (1) full use of current economic information relevant to decisions on criteria; (2) early exploration of how the criteria can serve to foster area or regional development; and (3) exploration of possible research on likely economic and social consequences of the criteria being developed.

7/ Virgil C. Herrick and Philip M. Raup, Organizational Problems in Developing Small Watersheds of Minnesota. Minnesota Agricultural Experiment Station Bulletin 437, January 1957.

I was particularly pleased by the special references made by Raymond Haik to the Twin City area. He underscored need for attention to aesthetics of recreational uses of water. I would add, we must view the metropolitan area as a geographic unit requiring an integrated approach to its many problems, including water supply, sewage disposal, drainage, recreational development, land use planning and development, transportation, renewal and redevelopment. We should seek a workable means whereby priorities for water development and use and water allocation can be established on a metropolitan area basis, to provide us with a quality urban complex for our expected future population of 4,000,000.

I believe we would all agree that the number of useful research projects we could propose would far exceed the water research funds available. More important, the useful research projects we could propose would use many times over the skilled researchers available to conduct such research projects. Therefore, we must try very hard to set research priorities.

Our efforts may appear unsophisticated and at times downright crude, but we have no choice but to set priorities if we are serious about further increasing the benefit to society from our research resources. I would predict that if administrators and researchers together set about the task of systematically establishing research priorities, they will be surprised at the unexpected advantages from their efforts.

Raymond Haik points out that management plans that result from the various studies and evaluation will just be gathering dust on a shelf unless there is developed at the same time an institution to carry them out. I predict that management plans will gather dust also if (1) those to be involved in the implementation are not involved in developing the plans, and (2) those to be directly affected by the plans are not represented in developing them.

In closing, I would like to raise several questions for Raymond Haik. Possibly he can respond to these in his published paper.

First, the differences in the availability of water and water problems within Minnesota were stress by Raymond Haik. Further, he points out that too often while we are waiting for the creation of a comprehensive institutional system we are not doing the things that can be done in smaller areas to more intelligently manage water use. Here we can ask what he has in mind.

Second, Raymond Haik cautions against jumping to the conclusion that the only way we can manage our water resources in Minnesota is by the creation of strong, centralized all-powerful agency of government. Recognizing the merit of this caution, I would ask him his views on the recently enacted Wisconsin water law which serves to centralize and strengthen water management functions.

Third, Raymond Haik suggests a number of studies for our possible consideration. It is appropriate to ask which of these studies, in his view, have the highest priority.

Prepared Statement by Sidney A. Frellsen

Some very interesting and provocative questions have been raised in the Principal Paper. In recent years, the importance of considering social and economic aspects in connection with all multi-purpose federal projects has been recognized and all Federal agencies concerned with the development of water projects are now required to not only consider these two phases but wildlife - agricultural - drainage phases as well. It may be true that some projects on state and local level have failed to give sufficient consideration to their social and economic impact.

Highway developments are taking great areas of agricultural and other lands away from their best use but the population increase and the industrial boom have increased highway use to such an extent that more, faster and safer highways are imperative. The Department of Conservation now has in force an agreement with the Highway Department for submission of new highway programs to the Department for review by the Divisions of Waters, Game and Fish, Forestry and Parks with opportunity to discuss suggested changes which would interfere less with game and fish habitat, encroach less on the public waters, take less land now used for forests by modifying or re-routing the road to other locations and to see that park and recreation lands are not reduced in their effective use for the purpose for which they were acquired and developed.

Since the distribution of rainfall is uneven and differs in quantity and duration, there naturally results areas of scarcity and areas of plentiful water supply. Diversion of water from an area of plenty to an area of scarcity is generally considered to be a good and practical method of conserving water for beneficial use. However, the legal problems of such a procedure are numerous and difficult. Minnesota law does not authorize diversion of water from one watershed to another except for mining purposes.

Minnesota in the past has relied on the Federal agencies, principally the Army Corps of Engineers and the Soil Conservation Service for projects related to flood control and erosion control. The Division of Waters does not presently have staff enough to properly follow through with the planning and field work necessary for an independent expression of the state's view on such matters although it did do so some years ago. The Division proposes new positions and funds in its 1967-69 budget request to bring the State back into a position of more thoroughly checking and participating in the work of these agencies in Minnesota.

Studies with various objectives are being proposed before the State makes any change in its water laws and administrative agencies in charge of water resources management. The general view seems to be however, that changes can be made first along the lines of the obvious needs and modified later if studies prove there is a necessity for modifications. Certainly, more authority is needed to enforce our water laws, to protect our water heritages from public and private encroachment, and to manage our waters -- dirty and clean as a unit, together with our lands -- to the extent necessary so that there will be a water heritage to pass on to future generations.

On every hand, we find the public brought into the planning of our water resource development. For example -- our watershed districts with local boards of managers can construct the necessary works for resource encroachment and development if there is local support and desire for such projects. Resource management on a watershed basis is a lifetime -- not a part-time job and must be done at the grass roots utilizing all the tools available through the Soil Conservation Service and other groups or agencies. Advisory Committees are used now with representatives of all segments of the local economy on the Committee.

The appropriative doctrine for allocation of water -- surface and underground -- certainly should be considered for possible use in Minnesota. Its principal value has been in the arid western states -- having started in California during the gold rush -- where a right to appropriate and use water was all important for without it no mining was possible. In the humid area, the doctrine creates more problems than it can solve. No taconite company operating in Minnesota has raised any doubt about its continuing authority to appropriate and use water even though no vested right has been or can be secured.

Permits are being transferred between companies for water appropriation and other purposes and whether or not there is a financial consideration involved in unknown -- but even the possession of a permit to appropriate water under Minnesota law is valuable -- it is not lost by non-use unless specifically provided in the permit. Revocation in such cases is only for violation of the permit provisions -- after due notice and public hearings. No permit of this kind has been revoked nor is it anticipated that any difficulty on this score will arise in the future. The companies who have furnished money for the development of taconite through mortgage loans have raised no question as to the operators' right to use water over the life of the operation.

There is no doubt in my mind that other benefits must be evaluated in determining the feasibility of a water project besides those upon

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which a dollar value can be placed. This is evident now in the opportunities given all agencies and organizations interested in our natural resources in participating in the decision making process through direct consultation with the promoters as well as through public hearings held by public agencies.

One of the problems faced by a state agency is the development of a staff competent to deal with the many and varied problems that come to it. I believe that in the Division of Waters we have done well in this respect, within the limitations of our annual appropriations. In addition to handling a wide variety of technical and administrative problems the agency must be able to interpret, implement, and apply state laws and department policies which are complex and have developed slowly over a period of years. It must be familiar with the water resources and problems of the entire state, and responsive to the needs of the many communities and of the state as a whole.

From time to time the Division has employed private consultants to assist it with specific, specialized problems. This has been to the advantage of both the state and the consultants. The use of consultants for State work is justified: whenever specialized experience, ability or equipment, other than that which is available in the agency, is needed; whenever a project of limited scope and duration requires more time and personnel than the agency, because of its limited staff, can assign to it; and when independent judgments, based on diversified background or experience, is required. The work of consultants should always be complementary to the normal work of the agency's staff. They should not be used to replace or reduce the staff. Too much dependence on outside assistance can only result in not developing the technical competence of the staff to deal with their normal functions. I believe this view is recognized and supported by the Federal Water Resources Planning Act, P.L. 89-80 in its provision for matching funds to train state personnel to carry out its activities, and by the following statement in the proposed Rules and Regulations being considered by the Water Resources Council.

"Consultant services are eligible (for matching purposes) only to the extent that the development of trained State personnel for comprehensive water and related land resources planning is not impaired."

The economic impact of any project is known soon after plans are announced by the opposition of so-called "self interest" groups and by articles in newspapers and other publications, promotional literature, hearings, etc. These same media bring out the social changes that will result depending to some extent upon the interest and activity of private groups such as the IWLA - Clean Air - Clear Water- Sportsmen's organizations and many others. The points raised by these groups, either for or against, are invaluable in developing projects or management plans that are intended to benefit the general public.

Lastly, we are all affected by the political decisions of governing bodies -- principally the Congress and the Legislature of the State

because it is the latter that determines broad policy, appropriates funds, create water agencies and determines their limitations as to personnel, functions and funds. The agencies can go no further in developing plans, policies and programs than the Legislature -- actcually the public at large -- will permit. Changes in all of these there will always be -- but the public must first feel the need -- for water resources management -- or any other phase of our economy. Perhaps a crisis must arise before action takes place and at such times studies take too long so organizations are changed -- crash programs are called for and funded -- perhaps without enough study. Such is our way of life -- but we can always change back or modify our thinking and the way our various agencies function. Change is always present -- in nature as in all things so let's be ready for it and progress with increasing knowledge, equipment and the desire of the public which after all pays the bills and calls the turns.

Prepared Statement by George E. Loughland

Yesterday, this conference heard a lot of facts and discussion about the waters of Minnesota, and the need for accelerated research in this wide field.

Today, Messrs. Haik, Vlasin, and Frellsen have spoken of water laws that must parallel the state's changing demands upon water uses and they, too, have spoken of the needs for research in that direction.

A little background for all of this might be of interest.

Minnesota has passed from an early phase of draining away some of its waters, to a current policy of saving what is available. And today we are, of necessity, and at an accelerated pace, paying attention to the qualities of water to make up for some past neglect and to keep abreast of the rapid rise in use of water in all of its modern aspects.

In a land devoid of population the early leaders sought settlers on the country's good agricultural land in order to help build the society of free men and women envisioned by the documents of the Revolutionary Period. By 1860, "swamp land" bills were introduced in the Congress giving such lands to the states. Though other good land was plentiful and cheap, Governor Ramsey in 1861, refers to the need of drainage of "swamp lands" in Minnesota. This indicates awareness of the handicap of stagnant waters on lands as being deterimental to the successful pursuit of agriculture, thus reflecting the experience of earlier settlers with the highly fertile wet lands west of the Appalachians. Drainage of "swamp lands" was a means to increase acreage of land that could be successfully cropped and thus provided an element of aid useful to the state's expanding population as well as being an overall economic asset.

This was the beginning of our drainage policy. Dollars, in the millions, were spent from 1858 to the 1930's to get rid of water.

This policy was to help enlarge the agricultural capacity of a major part of the bread basket of the world. Thus, by the 1920's the lands of our State were occupied by people scattered about small rural settlements, and the big city was not relatively large in territory, or in monitary worth, even though located adjacent to major streams.

In reaching for solutions to better land and water management note the state's early approach to this phase of water management from a monograph written in 1915 by the late Ben Palmer:

1858 -- private drainage corporations were authorized;

1866 -- township justices of the peace were given power to issue drainage permits;

1877 -- township supervisors powers replaced those of the justices of peace;

GEORGE E. LOUGHLAND attended Armour Institute (now Illinois Institute of Technology) and also worked on irrigation studies for The Arnold Company, an engineering firm. In 1910 he became associated with Northern States Power Company. Assignments in Minnesota were concerned with the construction of the Coon Rapids hydro-electric development placed in operation in 1914. Other engineering works in which he played an important part were: in Tennessee where he had charge of field engineering for a hydro-electric development near Nashville and for a 155 mile long, 100 kv steel tower transmission line built over the Cumberland Range; in Kentucky where he had charge of the construction of a steam plant at Louisville; in California where he directed field studies for potential water power and storage developments on the western slope of the Sierra Nevadas. Returning to Minnesota in 1924, he conducted engineering investigations at St. Anthony Falls and in 1926 he was appointed hydraulic engineer for Northern States Power Company in which capacity he supervised the operating, planning construction, and reconstruction of hydro-electric developments in Minnesota, western Wisconsin and South Dakota. From 1940 to 1951 he had executive direction of hydro and gas operations and of system planning, budget, transportation, and accident prevention matters. In 1951, he was appointed engineering consultant to Northern States Power Company. Just before retiring from North States Power in 1943 he developed the design and construction plan for the concrete apron structure built in 1954-55 at the Falls of St. Anthony. In 1956 he spend eight months in Turkey where he had charge of training Turkish engineers for initial operation of the 54,000 KW Seyham multi-purpose hydro-electric project near Adana. Other than his activities in the Engineers' Club of Minneapolis, his professional associations have been: North Central Electric Association (Chairman, Engineering Section, 1931-32); American Society of Civil Engineers, now a life member (President of its Northwest Section, 1934); Minnesota Federation of Engineering Societies (President, 1935-36). He was honored by the Engineers' Club of Minneapolis as "Engineer of the Year, 1962-63." He was appointed to the Minnesota Water Resources Board by Governor Freeman in March 1958; he has been board chairman since November 1959.

1883 -- county commissioners were given drainage authority;

1909 -- State Drainage Commission was established with "swamp land" improvement responsibilities;

1902 -- district courts delegated to handle intercounty drainage projects.

After 1915 the following legal changes came about:

1919 -- Saw the establishment of the Department of Drainage and Water (The State Drainage Commission was abolished);

1931 -- The Division of Waters was established in the Department of Conservation (The Department of Drainage and Water was abolished).

Today drainage procedures rest in the hands of the counties and district courts with engineering review provided by the Division of Waters.

A study of the above historical background of institutional management of water reveals that in the early 1900's leaders were aware that successful drainage could not be accomplished without a consideration of the whole basin or watershed involved. This concept appeared in Minnesota Law in 1917 in the Drainage and Flood Control Act. That Act has hampered, however, by poor operational provisions. Not until 1955 did the comprehensive watershed approach appear, encompassing all aspects of water management. This was the present Minnesota Watershed Act which provides for a separate local managerial group with powers to guide improvement projects within a given watershed, yet the county and municipality positions are not overridden.

These remarks speak of a frontier state and one of its problems as it developed. It is well to emphasize here the good work done by our educational system and its successful impact on the productive agricultural sector of the state's economy.

Since the 1920's, with the state's lowering farm income, and the appearance of crop surpluses, the phase of draining "swamp lands" for the family farm approached an end. Provisions for wildlife and recreation uses of the wetlands are already underway. This phase of water management is consistent with the modern need to conserve what we have now.

Depression, drought, new national policies in agriculture and public works, accelerating population increases, war years, all combined to put us on notice of an era that now emphasizes the need to conserve and hold water on the land. An early start for the retention of water, though not the primary reason for it, was the advent of the soil conservation movement started in the 30's to stop soil erosion. This principle is sound and should be vigorously supported.

The growth of the population began noticeably accelerating in the late 40's. In an expanding industrial complex largely because of technological advances, the state's population began to appreciably congregate at large metropolitan centers mostly situated near water courses. Water demands at these centers are increasing at rapid rates, hence long view appraisals must be continued and plans promptly implemented.

The latter part of this paper has dealt with the need for conserving and putting to effective use the waters that are potentially available.

Our State Legislators are keeping abreast of the rapidly changing aspect of this resource and, I am sure will, from time to time, alter the laws with as much foresight as is prudent and possible.

Obviously, research in this whole field of water quality, quantity and legal, is highly essential. In all of this, the emphasis must be on a long range basis to the end that waters' damaging potential is reduced, its qualities kept usable and that the quantity available will always meet the demand.

EDUCATION IN WATER RESOURCES

Principal Paper by Curtis L. Larson

We are currently witnessing the phenomenon of a sudden and pervasive public interest in our water resources. We who are professionally concerned with water have seen certain water problems developing long before the recent upsurge of public interest. But now, as never before, we have the opportunity of informing the general public how our water resources should be managed, and of gaining its support for getting the job done.

This sudden interest in water resources planning, projects and research has created a sharp increase in the demand for professional people trained in various aspects of water resources. Thus, we must be concerned with the problem of educating people to meet this need. First, we need to define the scope of "water resources." Also, what types of talent or disciplines are needed? What type of education is needed for each? What is the best way to provide this education? What types of programs are needed?

It might be appropriate at this time to recall the objectives of collegiate level education in general. First we must recognize that knowledge of facts is basic to all learning. Standard methods and procedures for laboratory study and problem solving are also essential, especially in the physical and biological sciences. But learning goes far beyond these things for the truly educated person. The late H. T. Morse, former Dean of the General College in the commencement address in March 1966, outlines several "Dimensions of Learning" beyond knowledge of facts and methods, essentially as follows: the ability to apply facts learned in one situation to a different situation; a capacity for critical thinking and analysis of existing information; an ability to integrate learning, i.e., to select the relevant portions of existing knowledge and combine them constructively; a set of personal and social values, or more simply, personal integrity, (I would include

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in this a high respect for the truth); and creativity (A single word, but very important).

These dimensions of learning are even more essential as one progresses into education beyond the bachelor's degree. This is not to say that further knowledge of facts and methods is not needed. Rather, these types of learning are the raw material and working tools, respectively. The real power to contribute to society is found in the five abilities listed above. Thus, the over-all objective of advanced education should be to develop these abilities in each individual to a high degree, in fact, to the limit of his intellectual capacity.

What is "Water Resources"? -- Water resources is a broad term including water supply, water needs, water use for a variety of purposes, water quality, water treatment, water projects, water conservation, in fact, any activity where water is of major concern. Actually, the term "water resources" has several meanings. We first used it to describe and measure the resource itself, how much, where and when. At the moment we are concerned with water resources as an area of professional endeavor, and therefore an area of educational needs. It is also an area of public interest.

Water resources is both too broad and too narrow to be considered a discipline. Rather, it is an area of specialization and application within many established disciplines. For example, it is appropriate to speak of specialized training in water resources engineering, in economics of water resources, in geology of water resources (hydrogeology), in water resources biology, and many others. Each of these is but a part of a discipline of long standing which was developed for other needs which still remain. The scope and power of each of the disciplines is far too great to justify its being devoted exclusively to problems of water resources. We now find that a wide variety of disciplines, or parts of disciplines, are being brought to bear on water problems. The sum of all these parts, then, is the broad area of application we now call water resources.

Originally, water problems were largely quantitative and usually involved some type of construction. Thus, they were considered to be mainly within the realm of engineering, the applied arm of the physical sciences. As water demands increased and began to approach the supply in certain areas, it became evident that water must be allocated among alternative uses, and thus the social sciences, especially economics, became more important. Furthermore, with multiple use of our waters, including recreational uses, estimating benefits has become a complex problem. We are finding also that changes in our legal and institutional structures are also needed, involving other social science disciplines. East of the Mississippi River, restoring and maintaining water quality is the overriding problem. The principal pollutants are organic and chemical wastes from municipal-industrial areas; sediment, livestock waste, fertilizer residues, and pesticide residues from agricultural areas. Preventing or correcting these forms of pollution is a major undertaking which involves several branches of engineering and a number of biological disciplines.

As indicated in the brochure, "Graduate Education in Water Resources," we at the University of Minnesota have attempted to clarify our thinking by dividing water resources education into three broad areas or categories (a) The Physical Sciences (including Engineering), (b) The Biological Sciences, and (c) the Social Sciences. We have listed also the existing departments who can or should contribute, realizing of course that some will make major contributions and that others, by their nature, will play a minor role.

Where appropriate, we have listed several areas of specialization for each department or discipline. Here you will note some overlapping of interest, which does not necessarily mean duplication of effort. These areas of specialization are, in most cases, not formalized within the department, but simply represent areas of interest and competency. At other universities these are likely to be quite different and in fact, the departmental arrangement may be somewhat different.

I believe that this division of water resources education into the three broad areas of the physical, biological, and social sciences is a very useful one. Perhaps the main reason is that no person can ever expect to become competent in more than one of these broad areas. An engineer in certain types of positions, for example, can greatly enhance his effectiveness by obtaining some knowledge of economics, government, ecology, or other non-engineering subjects. However, with techniques advancing on all fronts, to make an engineering graduate into a competent economist or biologist is at best a major overhauling job. It may be possible, but, in the meantime, he would be unable to keep up with advances in engineering. Likewise, I don't believe it is practical to attempt to make an engineer out of a biologist or a social scientist. On the other hand, a biologist or economist can profit by learning engineering terminology (as applied to water resources) and by knowing in general terms what is involved in engineering design procedures.

What Type of Education? -- Several basic educational questions should be decided before attempting to provide education for an area of specialization such as water resources. What educational level should be used? Should the educational program emphasize scientific or professional aspects? Does the area require a broad education or a high degree of specialization?

Vocational training in water resources is not the main concern in this paper. As water resource programs and projects grow, however, we will undoubtedly need many technicians to perform laboratory and field tests, to make surveys, to collect data, to handle our instrumentation needs, and to stretch the dollars available. I am not aware of any need for new types of technicians to serve in the area of water resources. In general, our vocational schools respond quickly to such needs. If gaps remain, in-service training can be offered to develop the skills needed. With this brief recognition that technicians are indeed essential, and assuming that they will be available to us, let us turn to the question of collegiate and professional education.

Should we attempt to do the job of water resources education at the Bachelor's degree level? I would say "No." To cover the entire field of water resources, including something of the physical, biological and social science aspects is obviously out of the question. In the process, we would create a generalist with no depth in any area, no specific or immediate capabilities, and no professional home. There appears to be little demand for such a generalist at the entrance level.

It might be possible to provide a significant undergraduate education in each of the three broad areas of water resources education, or portions of each. However, I feel this too would be unwise. One might, for example, consider undergraduate programs in water resources engineering, water resources economics, water resources biology, hydrology, etc. Some of these might appear attractive, but such a scheme raises some serious objections. One major objection has already been stated, namely that each of the existing disciplines has a breadth of application far exceeding water resources. A graduate of such a program would be limiting himself to a single area of application. Secondly, by emphasizing a particular application throughout a curriculum, the temptation to omit certain basic portions of collegiate level education, those which are not specifically needed for that application, sooner or later becomes irresistible. Finally, such an approach eventually leads to completely reslicing college education into fields of application, rather than disciplines, which for the most part are determined by the basic preparation required, and rightly so.

A student interested in a career in water resources should, in my opinion, first obtain a sound education in engineering, geology, economics, political science, biology, or one of a number of disciplines. If space in the curriculum permits some application to water resource problems, well and good. This will generally be inadequate, however, so that the individual must educate himself further in some manner. It follows then that post-graduate education in water resources is required. Whether this might be done at graduate colleges, through in-service training, or in some manner, we will defer for the moment. Instead let us consider the nature of the advanced education needed.

Should advanced education in the various areas of water resources emphasize the scientific and research aspects or the professional? This one is easy. I think we need both, or rather we need both types of people. It is difficult to prepare a person adequately for both types of work. Therefore we should encourage each individual to begin by making this choice, primarily on the basis of his abilities, so that he can plan his program of study accordingly.

Should advanced education in water resources be highly specialized or should it be aimed at broadening one's knowledge? The answer to the previous question determines, in part, the answer to this one. Those aiming for research must of course increase their depth of knowledge in their particular aspect of water resources. Ordinarily, they will also need to increase their understanding of the subjects fundamental to that specialty, which might be mathematics, chemistry or microbiology, to mention a few. In addition, I believe that research minded people as well

as others in the field of water resources should devote at least a small portion of their educational effort to gaining some knowledge of other areas.

Water resources is recognized as being a broad and interdisciplinary area. Undergraduate programs, for the most part, are relatively specialized. Thus, those preparing for more effective professional service in water resources should, in my opinion, make a special effort toward broadening their knowledge and viewpoints. This can be done in several ways which will be discussed later. At the same time, such a person will ordinarily need to devote equal time to increasing his competency in his major area. He may find that he has little if any time left for fundamentals. For the professionally oriented person at the Master's degree level, I would consider such a distribution of effort appropriate, provided the individual is well grounded at the bachelor's level according to present standards.

Methods of Providing Advanced Education -- There are several ways in which one's education can be continued beyond the bachelor's degree, including graduate school, extension classes and programs, short courses, in-service training, and informal individualized study. None of these can do the entire job, since individuals vary in their needs and abilities. Furthermore, in our advancing technology, one must continue to learn or fall behind. Also, one cannot hope to learn all that would be useful to him in any single program.

As one who is involved in graduate education and research in water resources, it is only natural that I would recommend graduate school for those who are capable of it. An M.S. degree requires about one-year of full time effort. One cannot lose but is likely to gain by obtaining the degree as well as the education it represents. A Doctor's degree requires a much greater quantity and a progressively higher level of effort. Thus, a doctoral program is considered worth the effort mainly for those in research or education. However, some find it worthwhile to undertake a broad doctoral program, perhaps in public administration, to prepare themselves for major administrative positions.

Extension or night school classes and programs are attractive because, for many, they do not interfere with one's regular work. This is an excellent way to obtain further education in a few specialized subjects. To go beyond this, however, entails problems. Even in a major urban area such as the Twin Cities, there are often not enough students of this type to justify a class, especially as one gets into specialized subjects. Thus, it is difficult to offer a sufficient number of such courses to build a Master's degree program. At present, only the School of Business Administration and the Department of Electrical Engineering at the University of Minnesota offer a complete Master's degree program through evening classes. The degree offered in Business Administration is the M.B.A., a professional Master's degree, rather than a Master of Science or Master of Arts.

Most units of the University do not offer a professional Master's degree. I personally feel that, in Engineering and especially in the water resources area, a Master of Engineering degree program would be a very useful addition to the M.S. program. I would propose that it consists entirely of coursework, including 6 to 9 credits of individual problems or studies, usually not involving original research. It would permit work in at least two supporting areas and might be similar to our present Plan B Master's degree program. Such a program would, in my opinion, be attractive to a goodly number of people who want more education primarily of a professional nature. To institute such a program, however, involved considerable study, discussion and planning, followed by agreement on the part of the faculty of the school involved as well as the Graduate School. Also, even if such a program proved popular for daytime graduate students, it may not be able to attract sufficient numbers for a night school program.

Short courses can be very useful in bringing new developments to the attention of a specific group, and for other purposes. In general, however, I would say that they do not lend themselves to intensive study of substantive material. One needs time to study and work on the subjects by himself between class meetings. Thus, I believe that to cram the equivalent of a college or graduate level course into a single week is to attempt the impossible.

In-service training, if properly organized and executed, is an effective way of developing capabilities within the organization. It does require that the organization devote some of its resources to the teaching function as well as to learning. If the organization is large enough to have or to hire the people to perform this function, well and good. It is only natural that, in the interest of efficiency, in-service training will include mainly what the employees need to know for the job and will tend to neglect other aspects or background necessary for a full understanding. The same is generally true for individualized informal study, except for those few who are truly intellectually curious. Nevertheless, individual study remains the one method of continued learning available to all, and should be encouraged and rewarded.

At the 1966 Annual Meeting of the Universities Council on Water Resources last July, Mr. Harry A. Steele, Assistant Director, Water Resources Council, Washington, D.C. noted that some government administrators have become discouraged with granting leaves for graduate education. They have found that those who go off to school tend to be dissatisfied when they return to their positions and after a time, move on to something else. The current shortages of personnel well trained in water resources has no doubt aggravated the situation. I would hope that academia is not at fault by encouraging students to develop abilities that are not useful in the outside world.

I would agree that this problem is real but would also submit that there are better ways to solve the problem than to discourage formal education. Perhaps some of these individuals are not being given sufficient opportunity to exercise their new abilities or to shoulder

greater responsibilities. This may require a special effort by the administrators and a willingness to accept change on the part of all personnel. A good salary increase is an obvious morale booster, but not always possible.

Another important benefit of graduate education is the informal interchange of ideas and viewpoints that occurs in the process. This can be especially true for those returning to school after a number of years of work experience. The day-to-day contact with people who have had experience in other organizations, coupled with the academic situation, can be most stimulating. The professors should and generally do become a party in this interchange and can also benefit from it. Thus, the educational process can serve to bridge the gap, if there is any, between the academic world and the world of application. I would hope that we never even approach a situation where the Universities provide graduate education primarily for future professors and other organizations do all of their own education beyond the bachelor's degree.

Programs for Water Resources Education -- Let us turn now to some of the specifics of formalized education in water resources. In other words, what kinds of programs are needed? Should degree or non-degree programs be favored? For those wanting advanced degrees, are the existing graduate school programs suitable? Are special graduate programs in water resources needed? How can the interdisciplinary needs of water resources education be provided in the graduate school context? Can those ten or more years out of college re-enter at graduate level? Each of these questions needs to be considered.

First, what about degree vs. non-degree programs of similar length? Several well known universities offer one-year, non-degree, post-graduate programs in selected areas. One university (Colorado State) has recently announced plans to initiate an International School of Water Resources Engineering in 1967. The school will have a duration of 12 months and those completing the requirements will be given a diploma, not a degree. Entrance requirements include a Bachelor's degree in engineering, but an above-average scholastic record is not required as in the case of graduate school. Tuition is relatively high, indicating that the school is intended to be self supporting.

I believe there is a definite need for such a school and hope that it will prove to be successful in every way. It appears to be well suited to the needs of many people, especially those (1) who need further education but not a graduate degree, or (2) who are not eligible for admission to graduate school. The program itself is attractive and will, I am sure, be appealing to planning and design engineers in water resources. Whether or not similar programs in the biological or social science aspects of water resources are available, I don't know. If so, I'm sure they would fulfill a similar need.

A one-year non-degree program is, in my opinion, a valuable addition to existing programs in water resources education. It does not, however, eliminate or reduce the need for strong and attractive graduate school programs in water resources. Neither does it eliminate the need for shorter programs, including summer institutes short courses, extension classes, and the like. I do not foresee that every major university would want to or be able to offer such a non-degree program.

For people interested in an eligible for an advanced degree, are the existing graduate school programs suitable? I cannot of course claim familiarity with graduate school programs throughout the country. Nevertheless, I feel safe in saying that, at most universities, the general requirements of the graduate school are sufficiently flexible to meet the needs of most students, both at the M.S. and Ph.D levels, I believe this statement holds for water resources, despite its interdisciplinary nature, provided one does not attempt to cover all aspects of water resources. In other words, an individual will experience no difficulty in planning a program if he chooses to take both major and minor in one of the three broad areas outlined earlier, and if adequately prepared in that area. Even if he chooses to broaden himself by taking a minor in a new area, for example, an engineering graduate student minoring in economics, this is generally possible.

The Graduate School here at the University of Minnesota has a useful mechanism for obtaining a broader education at the Doctoral level than is possible with the traditional minor. Instead of a minor, a doctoral candidate may elect to formulate a "supporting program," which may include course work in several disciplines that relate to the major and help fulfill his educational objectives. The student is not expected to develop a high degree of competency in each of these supporting disciplines. The supporting program for example, might consist of a social science program for an engineering or biological science major, a biological science program for a social science or engineering major, or a physical science program for a social science or biological science major. The supporting program can be used in other ways also; these are only some examples.

Some diversification is possible in the major field also, both at the M.S. and Ph.D. levels. Of course, a Ph.D. program cannot consist primarily of beginning level graduate courses. In any case, the foregoing does, I believe, show that fairly broad graduate programs can be formulated for those who want them, contrary to the common feeling that graduate programs and especially Ph.D. programs are necessarily highly specialized.

Next, what is the place of special, inter-disciplinary graduate programs in water resources? There are several such programs in existence, varying considerably in their objectives. The University of Wisconsin, for example, has a special M.S. program in "Water Resources Management." Applicants are accepted if they have a good undergraduate record in civil engineering, geology, agriculture, economics, political science or law, and from other fields. All students in the program are required to take specified courses giving them a minimum exposure to engineering, biological science and social science, including courses

in regional and water resources planning.

Cornell University has recognized Water Resources as one of 80 fields of graduate instruction and programs are being developed. A broadly based water resources minor is available for M.S. and Ph.D. candidates. A program in Water Resources Engineering has been set up and, I am told, one is Scientific Hydrology is in preparation. A number of interdisciplinary courses have been developed for the overall programs.

Kansas University has instituted an M.S. program in Water Resources Engineering. It is mainly within Civil Engineering, but is considered interdisciplinary since it includes some work in economics, law, and political science. Louisiana State is in the progress of developing an interdisciplinary Ph.D. program in water resources, with majors in engineering, geology, and economics. The University of Arizona has a graduate and undergraduate program in hydrology, but here a Department of Hydrology has been established. To my knowledge, it is the only such department in the United States.

The foregoing was not intended as a complete listing of graduate water resources programs. Rather, it was intended to show that there is a significant interest in such programs and that the approach varies considerably from one university to another. This is not surprising, since water resources is a new educational endeavor.

The question remains "Are special graduate programs in water resources needed? More specifically, are the benefits of such a program sufficient to justify a separate program and the associated extra effort required to operate such a program?" I have shown that existing graduate programs, which are department oriented, either are or can be made sufficiently flexible to meet the needs of water resources. It follows that special programs are not really necessary. Why then are efforts being made to set up special programs?

It appears to me that special graduate programs in water resources are being adopted to give the subject an identity of its own, a name that indicates directly the main objective of the program, to attract more students, and to provide a formal means of cooperation between disciplines. These are indirect but tangible benefits that should be considered. The technique is well proven in research. I refer to the practice of setting up a research institute or laboratory within a university or elsewhere and giving it a name and considerable freedom to operate on its own. We sometimes complain about proliferation of this sort, but must admit that it works, given an initial boost and aggressive management. In addition to the benefits of a special program mentioned above, it provides or should provide an effective and stable mechanism of cooperation between the various disciplines. True, good cooperation can be obtained on a voluntary basis, but it doesn't always work and may not last.

One the negative side, we have the extra effort and expense to operate an additional program. It could hamper other important efforts unless additional personnel are provided. Also there is the question whether such a program would merely draw students from other programs rather than attracting additional students.

An important factor to weigh when considering a special graduate program is the extent of the resources available at the University in question, especially in terms of faculty having direct interest in water resources. Such a program cannot be a one-man or one-department operation. There must be a sufficient number of supporting courses in the various disciplines, either available or in prospect. If thesis work is involved, as it will be in many cases, there should be faculty members qualified and willing to advise students in water resources studies, preferable with on-going research projects for financial support.

Should we embark on such a program at Minnesota? We haven't taken time as yet to talk seriously about this question, but perhaps we should. When we do, I am confident that we will consider carefully the questions that have been raised here and others that have not. If we do decide in favor of special programs, it is my opinion that, rather than have a single program attempting to cover all the major areas of water resources, we should provide separate programs for or within each of the three major areas. These might have titles as Water Resources Biology, Water Resources Economics and Public Policy, and Water Resources Engineering, in addition to the present program in Hydrogeology. Detailed study and discussion, however, may lead to a somewhat different breakdown.

I have indicated that lack of flexibility in planning graduate programs is seldom a problem. A more common limitation in laying out a good graduate program in an area such as water resources is the availability of suitable courses. This is not to suggest that every course in the program needs to be oriented toward water resources. On the contrary, the right courses in mathematics, chemistry, microbiology, statistics, etc., may be just as important, but these aren't always available either. At a major university, lack of courses should not be a problem, but it often is in some areas, especially at the Ph.D. level. Broadening one's objectives beyond a department may help to alleviate this situation somewhat. However, it appears to me that a conscious effort must be made to fill certain gaps. The social sciences, for example, have dozens of graduate level courses, but very few of these appear to be applicable to natural resource problems, which are largely in the public rather than the private sector.

It would appear also that a limited number of specialized, interdisciplinary courses or seminars are needed, of two different types. The first type is best explained by illustration. Cornell University has initiated a course entitled "The Physical Basis of Water Resources Planning," intended primarily for non-engineers and another "The Economic Basis of Water Resources Planning," primarily for non-economists. Similar courses dealing with biological aspects and the institutional aspects would be most useful for the uninitiated in those areas. Such

courses require careful planning if they are to be unspecialized, yet meaningful and worthy of graduate credit.

The second type needed would be courses that are designed to show how the various disciplines are combined or integrated in action programs. The titles of the courses would probably be something like Water Resources Problems, Water Resources Planning, etc. Various approaches including the seminar approach might be used here. In any case, to be successful, I believe that representatives of the key disciplines must participate both in planning and teaching the course. Also, the students must be required to do more than simply reading and listening and, if a planning course, must participate in a planning activity.

There are some additional problems that go along with graduate programs that I will mention briefly. One is the problem of re-entering colleges at the graduate level after 10 to 20 years away from the academic halls. Is it possible and practical? The answer depends much on the individual, his native ability, his original preparation, and to what extent he has continued to learn principles as well as procedures during during the intervening period. I personally feel that many such people can succeed in and profit by an M.S. program, especially in the area of water resources.

The problem of adequate financial support for people in this age group is difficult. Assistantships are actually designed for young graduate students who are either single or whose wives are employed. Persons with considerable work experience generally need financial support approaching their normal salary so that they can pursue their studies on a full-time basis. Universities cannot provide financial aid to this extent, but often can justify direct aid for thesis studies. It is encouraging that several agencies of the federal government provide a limited number of education leaves with full salary. A system of sabbatical leave with one half or more of regular salary, perhaps as a grant to make it tax free, plus some aid from the universities, would serve to increase education opportunities. There are of course a number of fellowship programs, but the stipends are generally not adequate for supporting a family. Also, these are generally competitive scholastically, and therefore tend to favor recent graduates.

Conclusions -- I will not attempt to summarize this discussion, nor do I have any firm conclusions that I can list for you. What I have done, primarily, is to raise a number of questions concerning the type of education needed in the area of water resources and offered some opinions on the methods that might be considered for fulfilling this need. If this discussion has stimulated your thinking along these lines, I believe it has been worthwhile.

Finally, I want to encourage each of you to give us the benefit of your thinking on this subject. We at the University do not claim to have the answers to questions that have been posed. I have stated my opinions freely, and I trust that the three gentlemen who follow will do likewise.

Many of you present are "customers" of this and other universities, since you make use of our "products," the people we provide with formal education. For several reasons, we find it difficult to become as familiar as we would like with your day-to-day problems of managing and developing our water resources. I hope, therefore, that this discussion will stimulate you to give us the benefit of your experience and observations on educational needs in this area, on the adequacy or inadequacy of education of the people you employ or work with, and on how you feel the educational job should be done. We shall be happy to hear from you in any manner that you find convenient and at any time now or in the future.

Prepared Statement by Edward Silberman

Curtis Larson and I were associated on a Subcommittee of the Water Resources Research Center dealing with education in water resources at the University of Minnesota. I believe that any major differences of opinion we may have had regarding policy disappeared in the discussions of that Subcommittee, and I agree in large measure with what he has written in his paper. I would like to make some comments relative to practical implementation of some of the ideas he presented based on my own observations.

The graduate students I advise have a bachelor's degree in civil engineering and are doing their graduate work in hydraulic engineering or in hydromechanics. Some of these students should be extending their learning experience by taking courses outside of the physical sciences so that they will be prepared to enter the water resources planning field in the broad sense. Unfortunately, this is not readily done as a practical matter.

The problem is that although many courses are offered by each department interested in water resources, few are suitable for the student who is a non-major in that area of science. In addition, there is usually a list of prerequisite courses to be mastered before a significant course can be taken. This is especially true at the upper graduate level. The program in water resources planning is, thus, prohibitive for a M.S. candidate and is very difficult for the Ph.D. candidate. Even if a potential Ph.D. were to devote his minor to economics, for example, so that he would be adequately prepared in that field, he would do so at the expense of excluding the biological sciences and such other social sciences as law or sociology.

We have found it possible to give some of our students background in the biological sciences by having them attend a summer institute on Lake Superior conducted by the School of Public Health and the Biology Department at Duluth. The equivalent of a one quarter general biology course is accepted as a prerequisite. Yet, the students appear to acquire much useful working information about biology and limnology. In return, their knowledge of fluid mechanics appears to be useful to the other students and instructors at the institute. It would be very desirable to work out a similar relationship with one or more of the social science departments.

We have tried to do something of this sort in Civil Engineering, too. Last spring quarter, the course in Water Conservation was revised. It previously was directed principally at physical science majors and required as a prerequisite three credits of hydrology which, in turn, required four credits of fluid mechanics as a prerequisite. All prerequisites were dropped, and the nature of the course was changed so that it would point up the major problems in planning for water resources development and would introduce discussion of the methods of attack from an engineering viewpoint. The course was advertised as being a common course for physical scientists, biological scientists, and social sciences. We think the course was successful, but we also know there is much room for improvement. It would be helpful if some of the departments in the social sciences and biological sciences would organize parallel courses from their viewpoints. It would not be necessary that these courses be directed only to water resources specialists, but they should have a good deal of material useful to the student studying water resources.

Our experience with our Water Conservation course points up the need for a subsequent course at a higher level dealing with actual planning for water resources development and drawing on a student's background in many disciplines. To offer such a course, it would be necessary to have an appropriate specialist on the staff. Our department does not have such a specialist, and I do not think any other department at the University does. With a purely voluntary, cooperative teaching venture such as we have not in water resources, it is difficult to sell any department on adding a specialist in such a restricted field with a small potential student body. This is a dilemma that is difficult to resolve.

EDWARD SILBERMAN received a B.C.E. with highest honors in 1935 and an M.S. degree in Civil Engineering in 1936 at the University of Minnesota. After completing his graduate study he worked as a hydraulic engineer in the area of planning and construction for a number of agencies until his entry into army service in 1941. Upon release from the service, he returned to the Civil Aeronautics Authority for a short period before coming to the St. Anthony Falls Hydraulic Laboratory, University of Minnesota, in 1946. He is now a Professor in Civil Engineering and Hydraulics, and since 1963 he has been Director of the St. Anthony Falls Hydraulic Laboratory. His research and teaching interests have included fundamental research and teaching interests have included fundamental fluid mechanics, hydrodynamics, and solution of practical problems in hydraulic engineering by experimental methods. He is a member of the American Association for the Advancement of Science, the International Association for Hydraulic Research and the American Water Resources Association, for which he edits the Water Resources Newsletter. He has served as president of the Northwestern Sec. of the Amer. Soc. of Civil Engineers and as a member of the Organizing Committee and Treasurer of the 5th U.S. Congress of Applied Mechanics.

I should note that I am talking about only two or three new graduate students each year from the Civil Engineering area at this time who would be interested in a broadly based water resources curriculum. If more courses are made available and continuing with the cooperative program we now have, there could possibly be twice as many students in the future. A few other students might take one or two courses from a water resources curriculum without following the entire program. With so few potential students, it is hardly possible to ask a department such as economics or law, for example, to institute nine or ten credits of courses in the water resources field. It would help, however, if other departments could offer courses in a somewhat broader area such as the economics or law of natural resources requiring not more than three to five credits of prerequisites. Classes might well be filled out by students from the social science or biological science areas.

I plead with the other interested departments, especially in the social sciences, to make some effort to implement our multidisciplinary effort in water resources.

Prepared Statement by Eugene A. Hickok

As a professional engaged with the technical problems of water resources evaluation, development and planning I am pleased to note the interest shown by participants to this conference with such diverse backgrounds, professions and fields of interest. As a "product" of both this and another university and as a "customer" of the products or people trained here I welcome this opportunity to present a viewpoint on the subject of "Education in Water Resources."

There is a real need for qualified people to work in the general field of water resources. In Minnesota this is demonstrated by the fact that more than 125 organizations representing every level of the Federal, State and local government, together with private citizens groups, industrial and conservation groups, and University sponsored departments are directly involved in or have an influence over the utilization of water in the state. The efforts to these organizations, sometimes due to a shortage of trained people, are many times conflicting and unilateral in nature. The positions assumed by these organizations are often not technically feasible or the legal and economic bases for the position has not been fully considered or carefully evaluated.

Of primary importance to the participants of this conference should be an intelligent program to assure the State will have qualified specialists not only to explore the technological aspects of water availability, quality and utilization but the socio-economic aspects as well.

It appears from an examination of the existing programs available in the University, as well as from a review of Curtis Larson's paper, that facilities are available to provide education in the technical aspects of water use. A practical way to effect this technical training is by actual performance of basic or theoretical research. That this method of education is a good one is generally accepted. A possible problem is that the relative ease of obtaining money for research and training projects will result in a neglect of study of possible improvements of existing techniques. Management and coordination of these research training projects within the State by the Water Resources Research Center is a necessity. Minnesota is fortunate in being one of the first states to organize such a Center, and after a good start we are watching to see how it develops.

With regard to opportunities for the future graduate in Water Resources. it has been the experience of our firm that many of the problems are more than purely hydrologic developments. Some studies involve preparing water resources management plans. These studies have legal and socio-economic aspects and are heavily weighted by their political feasibility.

There is a requirement in water resources management for students of all disciplines. It would seem logical that it should be the duty of the University to make this need known and to show that a person need not be a graduate of a curriculm labled "Water Resources Management" to find a place in the field.

In summary, the field of Water Resources Development is a most challenging and rewarding one; students should be encouraged to enter it. Minnesota is not short of water, but is short of qualified people to Provide sound water management.

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Prepared Statement by Roger R. Bay

Curtis Larson has discussed some very important aspects of education in water resources, applicable both here in Minnesota and in other states. I offer no great earth-shaking recommendations or suggestions, but I would like to elaborate further on a few points.

Broadening the students knowledge in areas outside of his specialty -- A broad background of course work in water resources is particularly important to today's student. Traditionally, education and research in water resources have been associated with the physical sciences because of our early need for describing and quantifying various hydrologic processes. Because of this, most students in the physical sciences have not been exposed to the biological and social areas.

However, the greatly increased interest in water resources research in the last few years has shown a real need for more knowledge in the biological and social sciences. In 1964, an American Geophysical Union group, the Committee on Status and Needs in Hydrology, listed 63 areas of research in the field of hydrology. Of the nine top priority items, four involved the biological sciences or combinations of the biological and physical sciences. We also know that much of man's influence on the water resource will be on or near the earth's surface through his interactions with plants and animals and because of assorted social and economic considerations. Thus, I suspect that we will see a greater interest in research and education in these two areas in the future, and we will also see a real need for people in the physical sciences who have a broad background in biological, economic, and other social aspects of water. And in turn, graduates in biological and social sciences must also have an appreciation and awareness of broad physical principles.

I know it is often much easier to talk of these desires than it is to actually "practice what we preach" with the many demands of our highly complex and specialized technical society. Yet it is the responsibility of university educators to provide this guidance to the students.

I believe the University of Minnesota has already made several important steps which encourage this diversification of graduate study. One is the supporting program, rather than the traditional minor, which is now available for Ph.D.'s This is logical and good. A second important step is the formation of the Water Resources Research Center, which has encouraged water resources research and education in all disciplines and has become a focal point for water resources interest in the University community. The broad program of the Center should encourage this trend toward interdisciplinary education.

ROGER R. BAY graduated with a B.S. in Forestry from the University of Idaho in 1953. He received the Master of Forestry degree from the University of Minnesota in 1954, and recently completed course work leading to the Ph.D. in Forestry, with specialization in watershed management, at Minnesota. He began his career with the U. S. Forest Service on a Ranger District in Montana. Since 1956 he has been engaged in watershed management research at the Grand Rapids field laboratory of the North Central Forest Experiment Station, where he is now project leader of the bog and swamp hydrology project. He is a member and past chapter officer of the Society of American Foresters; member of the Soil Conservation Society of America; recent state chairman of the Water Resources Committee, Minnesota Division, Izaak Walton League of America; and member of the American Geophysical Union.

Graduate programs for professionals not interested in research or teaching -- Curtis Larson mentioned the importance of professional training at the Master's Degree level for those who are not necessarily interested in research and teaching. The University might also want to consider the applicability of this concept to the doctoral level. I believe there is a real need to encourage additional graduate study beyond the Master's level for those people who may not be teachers or doers of research but who are administrators or users of research results. I think there is little question that our advancing society will call for more and more people highly trained in administration and direct production.

Special considerations might be given to a type of program where the student is able to take additional course work and spend less time on languages and individual research. Perhaps the requirement of original research and a thesis should be re-evaluated in this light as some universities are now doing in other areas of education where the doctoral candidate will be primarily a "user" of research results rather than a "producer" of research results. This type of program would require careful consideration and thought.

Preparing the researcher for problem-oriented research -- The majority of graduate students will be concerned with doing research and/or teaching. Many, if not most, of these future researchers will be employed by both public and private institutions which are primarily concerned with problem-oriented research, but research that has as its ultimate objective the answer to a specific water resources problem in a given region or in a given company.

I believe it is important that graduate students be trained in the various processes of problem selection and should know how these problems fit into the overall priority of research needs for a particular discipline and region. This can be covered in part through course work if such courses are available. Additional valuable training is gained by encouraging students to begin studies which will lead to the solution of logical parts of large, pressing resource problems in a particular state. In Minnesota, many of these problems have already been indentified by a recent Committee of the Water Resources Research Center. Thus, we have a general framework of research needs and it remains for the advisor and student to break down a particular need into meaningful and workable bits and pieces which the student can work on. This introduces the student to the process of problem selection, along with giving him experience in analyzing problems and carrying out detailed research and writing.

Training other than degree-oriented -- As the center of education in the State, the University should also be aware of the training and educational needs of various agencies and groups in the field of water resources and be prepared to help meet these needs. Short courses, seminars, perhaps specialized institutes of several weeks or months duration, etc., are all important tools to meet specific needs. The University has already sponsored seminars and a short course. Perhaps we should also consider longer courses or short-term institutes of a few to several weeks duration.

These offer some notable advantages. Costs and time away from the job are not particularly great, and many government agencies and private groups might encourage and support attendance by their employees. The institutes can also be long enough to delve deeply and adequately into specific subject matter and give the student enough time for thorough study. In addition, a three- or four-week course also brings the student in greater contact with the university environment, which can be a real advantage.

Most agencies and companies realize the importance of training men who have been out of school for some time. Yet, most cannot afford the time or money it requires to send staff men back to a university for a full-time quarter or semester of course work. Thus, it would appear that three, four, or five-week courses might be an acceptable compromise between the all too short, short-courses and the longer university quarters. Again, this is already being considered in other fields and several government agencies presently contract for short, intensive courses in specific disciplines.

Training for technicians, or non-professionals, might also be considered. By this I mean not vocational training as such, but highly specialized training in specific areas such as instrumentation or data analysis techniques. Here again, short courses of varying duration may or may not be useful.

The various water resource agencies in the state, private groups, and the University, must be concerned with these advanced training needs and must work together to anticipate future educational needs in the many fields of water resources.

QUESTIONNAIRE ON WATER RESOURCES RESEARCH NEEDS

During the winter months of 1966 about 350 people having an interest in water resources research in Minnesota were solicited by the Water Resources Research Center for information concerning needed areas of water resources research. A list of 160 research subjects bearing on water supply, water pollution, floods, land and water, lakes and water-based recreation, and social-economic aspects was compiled.

A questionnaire containing these research subjects was distributed to each Conference participant. The questionnaire was designed to give some indication of future research need priorities. Those in attendance were requested to assign one of the following priorities to each research subject: 1) high priority, 2) medium priority, 3) low priority, and 4) not needed. Forty Engineers, Geologists, Biologists, Administrators, representatives of Private Industry, Planners, University faculty members, and laymen responded to the questionnaire.

Based on the results of the questionnaire and considering water resources problems in Minnesota, additional research is needed most in areas bearing on social-economic aspects, water pollution, and floods, about in that order. Emphasis should be placed on the following specific research areas:

Methodology and criteria for water resources planning

Relationships between water resource agencies

Water law and institutions

Flood plain management

Methods for estimating future water resource needs

Financing water resource management

Water resources allocation among alternative uses

Economic impact from water resources development

Water resources policy making

Economic value of water resources in different uses

Travel and fate of chemical pollutants in surface waters and groundwaters

Identification of pollutants, their effect and importance

Process engineering and materials recovery processes to reduce pollution

Disposal and treatment of new and unusual pollutants

Water reclamation, renovation and reuse

Biological effects of phosphate pollution on lake waters

Limnological processes that alter the utility of lakes as water sources, fish and wildlife habitats and recreational uses

Ultimate disposal of wastes

Effects of streamflow regulation on water quality

Effects of land use on water quality

Rainfall-runoff relationships

Processing of hydrological data

Methods of alleviating spring flood problems through use of techniques to accelerate groundwater infiltration to prevent excessive runoff

Analytical, model and computer techniques to determine watershed hydrologic characteristics, flood routing, and for hydrologic system analysis

Basic water resources data network design

Effects of man's activities on floods

Statistical methods for analysis of hydrologic data

Correlation of drainage basin morphometry with runoff hydrographs

Surface water-groundwater interrelations pertinent to water resource management

Examination of the effects of artificial drainage on runoff

Time variations of streamflow which determine flood frequency, water yield and low-flow frequency

Effect of land treatment, various watershed characteristics, frost and snowmelt on floods and water yields from watersheds of a few acres up to 50 square miles

Recharge of aquifers under various watershed characteristics

Estimation of aquifer properties from geologic data

Mapping the aquifer characteristics of non-uniform aquifer layers

Artificial recharge of aquifers

Dynamics of groundwater flow systems

Increased water-use efficiency in agriculture

Water-soil-plant relationships

Soil classification in relation to water resources

The present level of effort or a moderate increase in effort would probably be sufficient with respect to the other research subjects listed on the questionnaire and given below:

Social-Economic Aspects of Water Resources

Methodology and criteria for water resources planning
Water law and institutions
Relationships between water resource agencies
Water resources policy making
Optimization of water resources development and management
Economic impact from water resources development
Water resources allocation among alternative uses
Economic value of water resources in different uses
Methods for estimating future water resource needs
Demand for water-based recreation
Effects of water-based recreation on lakes and streams
External costs associated with waste disposal
External benefits associated with flood control structures
Economics of temporary detention of wastes
Water rates and rate practices
Definition of water quality management areas
Costs to industrial users associated with various levels of water quality
Econometric methods to protect the recreation and aesthetic values which would result from water quality management
Definition of water resource management areas
Flood plain management
Stream specialization techniques--classification and zoning
Financing water resource management

Physical and Biological Aspects of Water Resources

Identification of pollutants
Effects of streamflow regulation on water quality
Effects of land use on water quality
Process engineering and materials recovery processes to reduce pollution
Travel and fate of chemical pollutants in groundwaters and surface waters
Disposal and treatment of new and unusual pollutants including radioactive substances
Ultimate disposal of wastes
Uses of water of impaired quality
Use of large-scale waste treatment facilities
Water reclamation, renovation and reuse

Chloride contamination from salt application to highways
Mechanics of reaeration of streams
Isotope cycles in water
Nature of pure water, including its chemical and physical structure and thermodynamic properties
Tolerances of major fish species in relation to pollution
Centralized suburban water supply and disposal systems
Effects of heat rejection by power plants
Increasing the assimilative capacity and the dissolved oxygen content of streams by artificial methods
Biologic processes affecting water quality
Soil properties related to waste disposal and water quality
Rural waste disposal
Factors controlling the chemical content of groundwaters

Recharge of aquifers under various watershed characteristics
Artificial recharge of aquifers
Estimation of aquifer properties from geologic data
Groundwater inflow into Great Lakes
Time of travel studies of groundwater movement in major aquifers
Delineation of areas of substantial groundwater discharge to major streams in Minnesota
Control of clogging in water wells
Use of saline ground-water resources
Changes in hydrogeologic properties of aquifers with time and under applied stresses
Application of analog and digital computers to groundwater systems analysis
Variations in permeabilities within major aquifers in Minnesota
Diffusion and dispersion in porous media
Correlation of base flow on streams and ground-water levels
Use of geochemical data in estimating hydrogeologic properties and yields of aquifers
Dynamics of groundwater flow systems
Field methods for evaluating vertical permeability of unsaturated and saturated deposits
Mapping the aquifers characteristics of glacial drift or other non-uniform aquifer layers

Rainfall-runoff relations
Statistical methods for analysis of hydrologic data
Processing of hydrologic data
Methods of unblocking ice from small channels
Surface water-groundwater interrelations pertinent to water resource development and management
Yields from small watersheds, ten square miles and larger
The process of interflow
Effects of man's activities on floods
Time variations of streamflow which determine flood frequency, water yield and low-flow frequency

Effect of land treatment, various watershed characteristics, frost and snowmelt on floods and water yields from watersheds of a few acres up to 50 square miles
Basic data network design
Surface areas or volume of water required to maintain fish production in farm ponds
Relation of precipitation patterns, frost, and snowmelt to flood peak discharge and runoff volumes
Correlation of drainage basin morphometry with runoff hydrographs
Detailed hydrologic analyses of Mississippi River headwaters reservoirs
The most practical design shape of drainage channels to minimize clogging by snow and ice and cause early break up of icing conditions in the spring
Methods of alleviating spring flood problems through use of techniques to accelerate groundwater infiltration to prevent excessive surface runoff
A simple method of computing accurate runoff rates from the flat lands of Minnesota (Red River Valley and similar areas) and from swamp and pothole waterheds
Unit-hydrograph simulation
Hydrologic systems analysis
Hydrograph synthesis from rainfall-runoff regulations on small watersheds
Examination of the effects of artificial drainage on a regional basis
Effects of basin characteristics and climatologic conditions on streamflow
Streamflow augmentation for water supplies and pollution abatement
Mathematical analysis of streamflow and precipitation sequences
Overland sheet flow
Estimating runoff from ungaged watersheds
Separation of streamflow hydrograph into its components, surface runoff, groundwater runoff, interflow and bank storage
Analytical, model and computer techniques to determine watershed hydrologic characteristics, flood routing, and for hydrogeologic and hydrologic system analysis
Probable maximum flood
Relations between flood frequency, valley physiography, and flood plain vegetation
Downstream projection and simulation of hydrologic information

Photosynthesis rates in fresh-water streams
Biologic effects of phosphate pollution of lake waters
Hydrology and ecology of lakes and potholes
Survey of water chemistry, productivity, and organisms of Minnesota lakes
Limnological processes that alter the utility of lakes as water sources, fish and wildlife habitats and recreational uses
Stratified flow in lakes, reservoirs, and large rivers
Water chemistry of bogs; physics of movement of bog water
Thermal and saline currents in lakes and streams
Biological relations of micro-organisms in flowing streams
Ecology of water-loving vegetation
Plankton ecology of Lake Superior

Effect of changing water levels on the biology of ponds, lakes, reservoirs and streams
Reliability of water in marshes and potholes for the production of waterfowl and furbearing species of mammals

Erosion, transportation, and deposition of shoreline sediments
The mechanics of ice formation and ice damage on the shores and shore structure of lakes and streams
Conditions of the stream and the bank materials which result in eroding banks
Erosion and sediment yield from land surfaces by precipitation
Physics of sediment transport in overland and channel flow
Methods for rehabilitating silting stream channels
Construction and use of recreational facilities
Mechanics of differential erosion by a degrading stream
Comparisons of production, transport, and deposition of sediment
Substitutes for rock as a rip-rap or revetment material
Sediment routing through channels, flood plains, and natural or artificial reservoirs
Scour by hydraulic structures
Soil erosion and sediment yield and transport

Evaluating soil moisture changes in watersheds
Field methods for evaluating vertical permeability of unsaturated and saturated soil
Evaluation and applicability of the universal soil erosion equation
Agricultural drainage and irrigation methods and design
Hydrology and hydrodynamics of the zone of vadose water
Tolerance of plants to free or gravitational water
Retention and movement of water in fine-grained material
Moisture migration within soils induced by thermal gradients
Salt balance of soil
Increased water-use efficiency in agriculture
Water-soil-plant relationships
Evaluation of parameters that affect evaporation from soil capillaries
Characteristics of the soil of importance in hydrology and watershed management
Energy relationships in and on the soil surface
High and low moisture levels and plant hardiness
Capillary retention of water in soil
Soil classification in relation to water resources
Fundamental properties of water as a substance related to absorbed water film thickness, clay-quartz aggregate bonding, capillary retention and adsorbed layers
Basic factors involved in soil freezing and thawing and their effect on runoff and soil movement

Precipitation as a hydrologic variable--its space and time variations
Effects of man-made influences on climatology
Raingage networks for a comprehensive watershed research
Incidence and spread of drought

The effects of macro- and micro-climate, water intake, storage, transmission and recharge on evaporative and transpirative water losses
Interplay of climatic fluctuations and hydrologic phenomena
Seasonal climatic effects of temperature and precipitation on ground-water availability and quality
Precipitation patterns and frequency analysis
Temperature of water effect on plant growth
Vapor flux and evaluation of the hydrologic budget
Effects of interception of precipitation by vegetation on transpiration
Absorption and transmission of water by plants
Environmental effects on the accumulation, transport, and redistribution of snow
Effects of physiographic features on precipitation
Precipitation on large lakes
Environmental modification caused by ice and snow
Suppression of evaporation and transpiration
Atmospheric sources of solids and solutes
Areal distribution of storm precipitation
Water transfer by evapotranspiration: mechanisms and amounts
Improved methods for calculating evaporation and heat transfer from water surface
Routing of liquid water through ice and snow
Mass energy exchange at the interface between the atmosphere and snow and ice surfaces
Relation between potential and actual evapotranspiration

Other areas of needed research specified by those completing questionaires are given below:

Normalizing by multiple use concept

Control of use of water by rate variation

Cooperative effort by industry

Methods of preventing fish winterkill in shallow lakes

Methods for pricing recreation use of waters

Functional relationship of soil characteristics of importance in hydrology and watershed management

Application of small plot data to runoff and soil loss from watersheds

Relationship of various methods of streamflow-frequency computations

Effects of urbanization on streamflow

Improved methods of measuring streamflow quantity

Studies of rainfall infiltration loss rates

Effect of shoreline (cabins, etc.) on pollution of lakes, zoning for septic tanks, central sewage treatment