Proceedings of Conference on Ongoing Water Resources Research in Minnesota, March 1970

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WATER RESOURCES RESEARCH CENTER
UNIVERSITY OF MINNESOTA
GRADUATE SCHOOL

CONTENTS

Foreword

On March 26, 1970, a Conference on Ongoing Water Resources Research in Minnesota sponsored by the Water Resources Research Center was held in the North Star Ballroom, Student Center, University of Minnesota, St. Paul Campus. About 75 people attended the Conference. The objective of the Conference was to acquaint those concerned with water resources in Minnesota with the nature of ongoing water resources research activities in the State. Representatives from 14 organizations having research programs participated in the Conference. Most of the papers presented at the Conference are published in this Bulletin in the order in which they were presented.

RESEARCH ACTIVITIES OF THE WATER RESOURCES RESEARCH CENTER

BY

WILLIAM C. WALTON 1/

Before describing the research activities of the Water Resources Research Center, I will present a brief review of information concerning efforts and expenditures for water resources research conducted in Minnesota 1963 through 1968 to provide a frame of reference for our Conference speakers' remarks. According to a recent survey made by the Center, total research effort in terms of number of ongoing projects and man-years of effort reached a peak in 1967; financial support for water resources research has declined since then. The number of ongoing projects rose from 53 in 1963 to 96 in 1967 and was 73 in 1968. Total expenditures increased from $629,000 in 1963 to $1.8 million in 1967 and were $1.5 million in 1968. Man-years of effort rose from 43 in 1963 to 98 in 1967 and was 81 in 1968.

The work of University and college student research assistants and research associates accounted for about 40 percent of the total man-years of effort in 1968. The work of professional and sub-professional employees of Federal, State, local and private organizations accounted for about 60 percent of the total man-years of effort. The average expenditure per project rose from about $13,000 in 1963 to about $21,000 in 1968.

In general, research effort by all measures has been consistently high in the following 4 research topic categories: Water Cycle, Water Quantity Management and Control, Water Quality Management and Protection, and Engineering Works.

Expenditures for research effort in the category Water Quality Management and Protection comprised about 60 percent of the total expenditures in Minnesota in 1968. No research effort has been reported in category "Water Supply Augmentation and Conservation" and very little has been reported in category "Scientific and Technical Information." There has been little research effort in the following subcategories: Effects of Man's Related Activities on Water; Ultimate Disposal of Wastes; Water Treatment; Cost Allocation, Cost Sharing, Pricing, and Repayment; Non-structural Alternatives; Data Acquisition; and Evaluation, Processing and Publication of Resources Data.

During the period 1963-68, the University of Minnesota was the organization conducting the greatest amount of research with Federal Agencies; State and private Colleges and private enterprises (others); and State Agencies following in that order. In 1968, expenditures by the University of Minnesota, Federal Agencies, State Agencies and others were $637,000;

1/ Director, Water Resources Research Center, University of Minnesota

$506,000; $46,000; and $304,000 respectively. While the University of Minnesota conducts the largest amount of research, much of this research is funded by Federal Agencies and the State. For example, in 1968 funding of research projects conducted at the University of Minnesota was about as follows: Federal - $525,000 and State $95,000.

The Department of Agriculture and the Department of the Interior are the Federal Agencies carrying on the bulk of water resources research programs in Minnesota, followed by the U. S. Army Corps of Engineers in the Department of Defense. The Agricultural Research Service and Forest Service account for the major share of research in the Department of Agriculture. The Geological Survey and Federal Water Pollution Control Agency account for the major portion of research by the Department of the Interior.

Within the University of Minnesota, water resources research has been carried on in 16 different divisions representing the biological, physical and social sciences. The St. Anthony Falls Hydraulic Laboratory has led in research effort followed by the Department of Agricultural Engineering, and the Department of Entomology, Fisheries and Wildlife. A significant increase in Research Effort over the period 1963-68 has occurred in the Limnological Research Center.

Now, a few words about the research activities of the Water Resources Research Center. The Center does not conduct research nor does it have research facilities. It plans and arranges for Divisions of the University to conduct competent research of either a basic or practical nature in relation to water resources. The Center strengthens research activities of departments and schools and assists the University in its efforts to provide a well-balanced overall water resources research program.

During the school year ending June 1968, there were about 98 students majoring in water resources related fields. About 44 water resources oriented students graduated in June 1968. During 1968, about 50 students received part-time employment or other financial support through Center programs. The Center has been helpful in developing 20 new courses bearing on water resources, a new graduate option in hydrogeology, and a program of graduate education in water resources.

The Center started in 1965 with 7 research projects in progress; an average of 14 research projects have been in progress during 1966-70. Principal Investigators have completed 17 research projects. Sixteen reports are related to these research projects sponsored with funds made available to the Center by the Office of Water Resources Research, U.S. Department of the Interior, in connection with Title I of the Water Resources Research Act of 1964.

Office of Water Resources Research grant expenditures by the Center have increased from $52,000 in 1965 to $315,000 in 1969, largely as a result of the steadily increasing Matching Grants. In 1965, 72 percent of the Water Resources Research Centers in the Nation received less funds than did the University of Minnesota from OWRR, whereas, in 1970, 90% of the Centers received less funds than did Minnesota.

In 1969, 65 percent of expenditures were for salaries and wages; 8 percent were for non-expendable property and expendable materials and supplies; and 27 percent were for other costs including indirect costs and fringe benefits. About $79,000 has been encumbered for nonexpendable property assigned to Divisions of the University. Expenditures for salaries and wages have been equally divided between the categories of Principal Investigators and Director; Research Associates and Fellows; Graduate Students and Undergraduate Students, Technical Assistants, and Clerical Assistants.

OWRR funds have been allocated by the Center to the following Divisions of the University of Minnesota: Department of Botany, Limnological Research Center, Department of Agricultural Engineering, School of Forestry, Department of Soil Science, School of Public Health, Minnesota Geological Survey, St. Anthony Falls Hydraulic Laboratory, Department of Agricultural Economics, Department of Horticultural Sciences, and Department of Anthropology.

The following state and private colleges have participated, or will starting in 1970 participate in the Center's research program: St. Mary's College, St. Cloud State College, Bemidji State College, Winona State College and Gustavus Adolphus College. All state and private colleges in Minnesota are encouraged to submit matching grant research project proposals to the Center for possible OWRR funding. The trend of increased participation of state and private colleges in the Center's program, hopefully, will continue in the future.

The main thrust of the Center's program to date has been directed toward: determining groundwater contribution to streamflow and its relation to hydrologic basin characteristics; appraising the effect of potholes on groundwater resources; evaluating induced infiltration of water in streams; determining soil moisture movement induced by winter thermal gradients; establishing a practical baseline of water quality for Lake Superior through the use of the continuous plankton recorder technique; the analysis and interpretation of existing Federal, State, and local water resources legislation and court decisions and ways and means for improving water laws in Minnesota; ascertaining the physiological and ecological requirements of the algal species responsible for severe blooms on lakes scattered throughout the State to assist in controlling the excessive productivity of polluted lakes; determining methods for rainfall-runoff predictions which are based on the physical characteristics of ungaged small watersheds; reconciling and integrating water quality management with the ecological and social-economic objectives of the total water resources of Minnesota; formulation of an economic optimizing model for water quality and sewage disposal on selected stretches of the Upper Mississippi River; investigation of programs that appear to have special merit relative to hydrologic analysis for determination of design floods and for design of spillways and related structures; investigation of soil dynamic changes when interacting with water to assist in solving water problems such as infiltration, water spreading and flow properties in soils; determination of runoff-time distribution for a variety of watershed sizes and slopes; determining the role of bottom sediments in the phosphorus cycle for lakes of different types to assist in de-

vising corrective measures for overfertilized lakes; development of techniques that will pinpoint polluted areas in reaches of the Upper Mississippi River where algacides might be profitably administered to control pollution; investigation of mist irrigation as a method of reducing water stress in potato crop production and thereby reducing transpiration; investigation of the mechanics of soil moisture movement and retention to assist water resources developers and managers in estimating recharge to groundwater reservoirs and the effect of soil moisture movement on surface water runoff; study of citizens groups involved at the grass roots to improve the water resources environment in Minneapolis-St. Paul, Miami and environs, and two other metropolitan areas and environs in the USA; and determining existing ecological conditions in the Mississippi River near Monticello, before operation of a large nuclear power plant and monitoring the environmental changes due to the thermal discharge from the power plant generator.

The Center's FY 1970 program ($329,000) will include the following 7 new research projects: Alleviation of Lake Pollution by Utilization of Aquatic Plants for Nutritional, Medicinal or Industrial Purposes; Predicting Peak Flow of Small Watersheds by Use of Channel Characteristics; Mathematical Simulation of a Large Watershed Using the Systems Approach to Quantity and Quality Analysis; Spatial Variations in the Perception of Water Resources and Water Problems in South Central Minnesota; Area Financing of Water Resource Development; Social and Economic Factors in the Adoption by Industry of Water Pollution Control Measures; and A Survey of Attitudes Towards the Mississippi River as a Total Resource in Minnesota.

For several years the Center has known that the need for research concerned with the social-economic-political aspects of water resources exceeds the need for research concerned with the physical-biological aspects of water resources. However, in 1967, not a single research project proposal concerned with social aspects was submitted to the Center. In contrast, the Center's 1970 program includes 7 social-economic projects whose support will constitute about 46% of the Center's budget. This trend of increased emphasis of the Center's research program on social-economic-political aspects of water resources is expected to continue at least during the next five years.

In the past, the Center has not sought funds from granting agencies other than the Office of Water Resources Research to avoid competition with other Divisions of the University. State agencies have not financially supported the Center. Hopefully, in the future, State agencies will find it possible to provide funds so that the Center can be more responsive to state water resources research needs.

The University of Minnesota through its Water Resources Research Center, has demonstrated its interest and its capability during the past six years, and it is willing to further develop a truly outstanding water resources research facility for the State. It has provided the mechanics for unifying water resources research throughout the State. The Center is grateful to the speakers of this Conference for sharing information concerning ongoing research projects.

WATER RESEARCH PROGRAM OF MINNESOTA POLLUTION CONTROL AGENCY

BY

JOHN P. BADALICH 1/

The Minnesota Pollution Control Agency and staff is charged with the administration of this State's water pollution control program. Many State agencies are involved in water resources management in varying degrees and we often hear the criticism of overlaps, duplication and the general confusion regarding water responsibility and law. We would like to suggest to you that water pollution control is a matter of policy development, regulation, surveillance, and enforcement that can be, and we feel should be, handled separately and apart but coordinated with other State and Federal agencies.

We are not a research oriented agency in the normal sense of the word, but our policies, regulations and everyday functions are heavily dependent on somebody else doing some research, for example to establish parameters and acceptable limits for water quality, new and refined analytical methods, analytical hardware, advanced waste treatment methods, surveillance techniques and so forth. We do not feel that basic research should be one of our functions except as it may be directly related to one of our ongoing activities.

The dictionary defines "research" as the diligent and systematic inquiry or investigation into a subject to discover facts or principles. In this broad sense we could consider such things as our water quality surveillance program to be "research" but its real purpose is more aligned with enforcement as related to our particular use. This is not to say that some other institution could not make use of the data we accumulate and apply it to basic research and we invite them to do so. Our feeling at present is that research is properly the function of such institutions as Universities, the Federal water quality laboratories, private institutions such as the proposed Fresh Water Biological Institutes and others.

I would like to discuss with you the projects which we currently have underway or proposed as a part of our on-going program where research or "investigation beyond our minimal needs" is involved. In most instances we have made use of consultants to provide this added input. The reasons for this are many, but basically it is that we do not feel it proper to divert our limited staff resources away from critical program needs.

North Star Project

Several months ago the North Star Research and Development Institute approached the Minnesota Pollution Control Agency (MPCA) with a research proposal to investigate the use of reverse osmosis for the purpose of treating metal finishing wastes to reduce the pollutants in the effluents

1/ Executive Director, Minnesota Pollution Control Agency

from such plants and to recover valuable plating materials. North Star was looking for two things from the MPCA 1) a sponsor and 2) 30 percent matching funds for a Federal grant which they felt certain would be offered.

The Agency was sympathetic toward the project and acknowledged the need for new methods to treat these troublesome wastes but felt that this was a rather limited benefit type project and the match money should properly come from the plating industry itself. We agreed to sponsor the project as grant recipient but provide no State funds. The project is well underway now on this basis and we are happy that we can lend assistance as sponsor even though the idea was not our own. Our particular input to this project is limited to administering the grant funds received from Federal Water Pollution Control Administration.

Serco Project - Aerated Lagoons

The MPCA is responsible for the review and approval of plans for construction of sewage and waste treatment works of all kinds. In recent years the use of mechanically aerated ponds for the stabilization of organic wastes has been proposed and tried at four locations. Approval of these facilities was granted on an experimental basis and operational data has been limited and of a conflicting nature. The Agency felt that this treatment method had general application and could also provide important benefit for pre-and post-treatment needs and further that it was not entirely equitable to place the demonstration of the methods application entirely on the communities.

It was recommended to the Agency that they sponsore and pay for research study to specifically establish design paramters, i.e.: allowable BOD loadings, air requirements, detention times, number of cells, etc. by investigating the existing Minnesota installations with the further purpose of developing operation and maintenance information.

The contract for these studies was awared to Serco Laboratories entirely from MPCA funds to make these studies. The project was for one year and a total of $16,000 with scheduled completion by June 1970. Design parameters are dependent to some degree on climate and information on this type design in northern climates was lacking. It is clearly a research type study but very specific to our sewage works program needs.

Pesticide Project - EBS

There has been much concern expressed recently over pesticide levels in the Great Lakes, particularly in the lower lakes and not a great deal of information is known concerning inputs of pesticides to these lakes. The Upper Great Lakes Governor's Conference on pesticides requested Federal assistance in the form of a grant offer from Federal Water Pollution Control Administration.

Our involvement concerns only Lake Superior where no problem is apparent at present. Nevertheless the potential for a threat to the ecology exists and it is incumbent upon us to investigate in some detail the present situation.

Accordingly a grant of $15,000 plus a state match, to come from MPCA funds of $8,000 for a total of $23,000 has been accepted by MPCA and a contract has been recently negotiated with Environmental Biological Services to study this matter. Very briefly the project involves monitoring major and minor tributaries to Lake Superior to determine the extent of the problem and how the contaminants move from land to the streams and lakes. It is proposed to monitor the waters directly and to utilize captive organisms (clams) as biological concentrators. By identifying the sources and manners by which pesticides move into Lake Superior the information necessary to control such inputs can be obtained. This project is scheduled to cover a one-year period and should begin within about one month.

Lake Minnetonka Project - Harza Engineering Co.

The MPCA and the Water Pollution Control Commission before them had a grave concern for the fate of Lake Minnetonka because it is one of the most heavily-used recreational lakes in the State and further because it receives the treated effluents from several major sewage treatment plants.

The Agency adopted a policy toward the removal of all sewage effluents from this lake and elected to conduct a comprehensive study under contract with a consultant, to investigate a few basic questions; 1) What is the status of the lake today? 2) What should it be in the future? and 3) How will this goal be obtained?

The Agency envisioned a study that would be comprehensive in the areas directly related to possible enforcement action with very limited emphasis on the in-depth study of the lakes ecology. The Lake Minnetonka Conservation District was concerned that any study be conducted in sufficient detail to make the results useful for long range purposes and to study in great detail the ecology of the lake with particular emphasis on water and nutrient balance. Private funds were raised totaling $100,000 which the District provided as a gift to the MPCA to be combined with its $60,000 to incorporate into our study of all of those things which the District felt warranted detailed study. The Agency felt that such detailed study would be highly advantageous and with local participation could be incorporated to both of our advantages.

The contract was awarded to Harza Engineering Company of Chicago with the concurrence of the Minnetonka Conservation District and the Minnehaha Creek Watershed District. Harza has contracted with Dr. Megard of the University of Minnesota to provide the limnological and biological input and with the local firms of E. A. Hickok and Associates and Barr Engineering to provide selected inputs to the study. The study is well underway and scheduled for completion in December, 1970. The MPCA has an active part in this study also by providing regular nutrient monitoring of sewage treatment works in the watershed.

One final study associated with the taconite discharge to Lake Superior is being proposed by the MPCA with the assistance of a Federal Water Pollution Control Administration grant. This project if approved will involve the study of Lake Superior tributary waters and certain East Mesabi Range streams to establish the reliability of Grumerite-Cummingtonite as a taconite tailings indicate by comparative X-ray diffraction analyses.

In addition the study would investigate reported taconite tailings (fines) drifting in Lake Superior in the vicinity of Reserve Mining Company for physical and chemical determinations. This particular matter is the subject of a Federal-State Enforcement Conference on Lake Superior as you know.

We are proposing to conduct much of this study in-house if at all possible because we feel it offers an opportunity for our staff to gain valuable experience, particularly in the use of scuba equipment and under water photography. Recent levels of enforcement activity however may not permit the entire project to be conducted by our own staff.

In conclusion, I believe the projects outlined above clearly indicate that research or investigations of this type are necessary to provide the Agency with the needed data to properly carry out its functions in the control, prevention and abatement of water pollution in the State of Minnesota.

WATER RESOURCES RESEARCH CONDUCTED IN MINNESOTA BY NORTHERN STATES POWER COMPANY

By

ARTHUR V. DIENHART 1/

Northern States Power Company (NSP) has a significant interest in Minnesota's water resources for several reasons. As a consequence of operating electrical power generating plants, NSP is a non-consumptive user of significant quantities of a surface water for condensing steam from turbine-generators. As a public-service organization head-quartered in Minnesota and having the majority of its customers in Minnesota, NSP's corporate welfare is substantially influenced by the natural and economic resources of Minnesota and the interrelationship between these resources. As a technically oriented enterprise, NSP has a strong motivation to support the development of factual knowledge concerning water resources management, so that this knowledge can replace the speculative and emotional approach which frequently is applied.

The Minnesota Water Resources Research Center uses the research classification system developed by the Federal Council for Science and Technology. NSP's research efforts fall into Category V, "Water Quality Management and Protection," and involves identifying and controlling waterborne wastes from NSP facilities so that these discharges do not damage the aquatic environment.

As is the case with any manufacturing process, electric-power generating plants produce liquid, gaseous, and solid wastes, all of which require management so that they do not have a detrimental effect upon the environment. The following discussion will focus specifically on liquid discharges from NSP's major generating plants in Minnesota. Subjects excluded from the scope of this presentation are studies at NSP's smaller generating plants; studies conducted at places outside Minnesota; and studies in which NSP has a cooperating role but in which the primary funding and direction is the responsibility of another organization. Also excluded are the atmospheric and terrestial monitoring studies conducted at NSP's plants.

Although NSP routinely monitors the liquid discharges from its generating plants to determine a variety of parameters, the only waterborne waste of any significance from NSP's plants is heat. This waste heat can be managed and controlled with present-day technology, but because such controls are a significant factor in the operation of a power plant, it is important to monitor the effects of the thermal discharge to determine that detrimental environmental effects are not occurring and to provide regulatory agencies with data to guide them so that hopefully they will not require expenditures for thermal-waste treatment equipment which does not result in any significant environmental improvement.

1/ Assistant Vice President, Northern States Power Company

This paper will summarize the three principal water monitoring programs presently being conducted by NSP for its King, Monticello, and Prairie Island plants. The geographical location of these plants is shown in Figure 1. The programs measure physical and chemical parameters of the surface waters and include studies of the macroinvertebrate, algal, and fish populations (Figure 2).

The aquatic monitoring program at the King Plant on Lake St. Croix at Oak Park Heights began in 1966. Two years of preoperational monitoring data were collected. The plant was placed in commercial operation in the spring of 1968, so the monitoring program presently has measured two years of operational conditions. The program is continuing, and the aquatic monitoring portion of the King program is expected to cost $110,000 for work in 1970.

The geographical area included in the King water quality sampling program is shown in Figure 3. About 660 cfs of cooling water is withdrawn from and returned to Lake St. Croix. The nominal temperature rise through the condenser is approximately 18°. Cooling towers are used in the summer months to comply with permit requirements of the Minnesota Pollution Control Agency. Holding basins are used to treat the small quantities of chemical wastes before discharge.

Annual reports for the years 1966, 1967, and 1968 have been distributed to interested agencies and persons, and the report for 1969 is in the editing process. The data collected thus far by the program indicates that waste discharges from the King Plant have had no adverse effects upon the environment. A special effort will be made in the King program during the summer of 1970 to determine the environmental benefits, if any, of using cooling towers to reduce the termperature of the discharge to Lake St. Croix. Some tests conducted during 1968 and 1969 indicated that the temperature effects on the lake are insignificant whether the cooling towers are operated or not.

In 1968, NSP began a water quality monitoring program in the Mississippi River upstream from Monticello to determine preoperational conditions in the aquatic environment which might be affected by the discharge of liquid wastes from the Monticello Nuclear Generating Plant, scheduled to be placed in service in 1970.

In contrast to Lake St. Croix, which is a wide, deep, slow-flowing reservoir, the Mississippi at Monticello is not part of a reservoir but is subject to relatively wide variations in flow resulting from natural causes and from the operation of upstream reservoirs. The same general ecological parameters are being measured at Monticello as at King (chemical and physical properties, invertebrates, algae, and fish) but the techniques of collection have been modified to accommodate the different hydrologic conditions.

The geographic scope of the Monticello studies is shown in Figure 4. The maximum cooling water flow is 645 cfs, and the nominal temperature rise through the condenser of the stream turbine is approximately 27°.

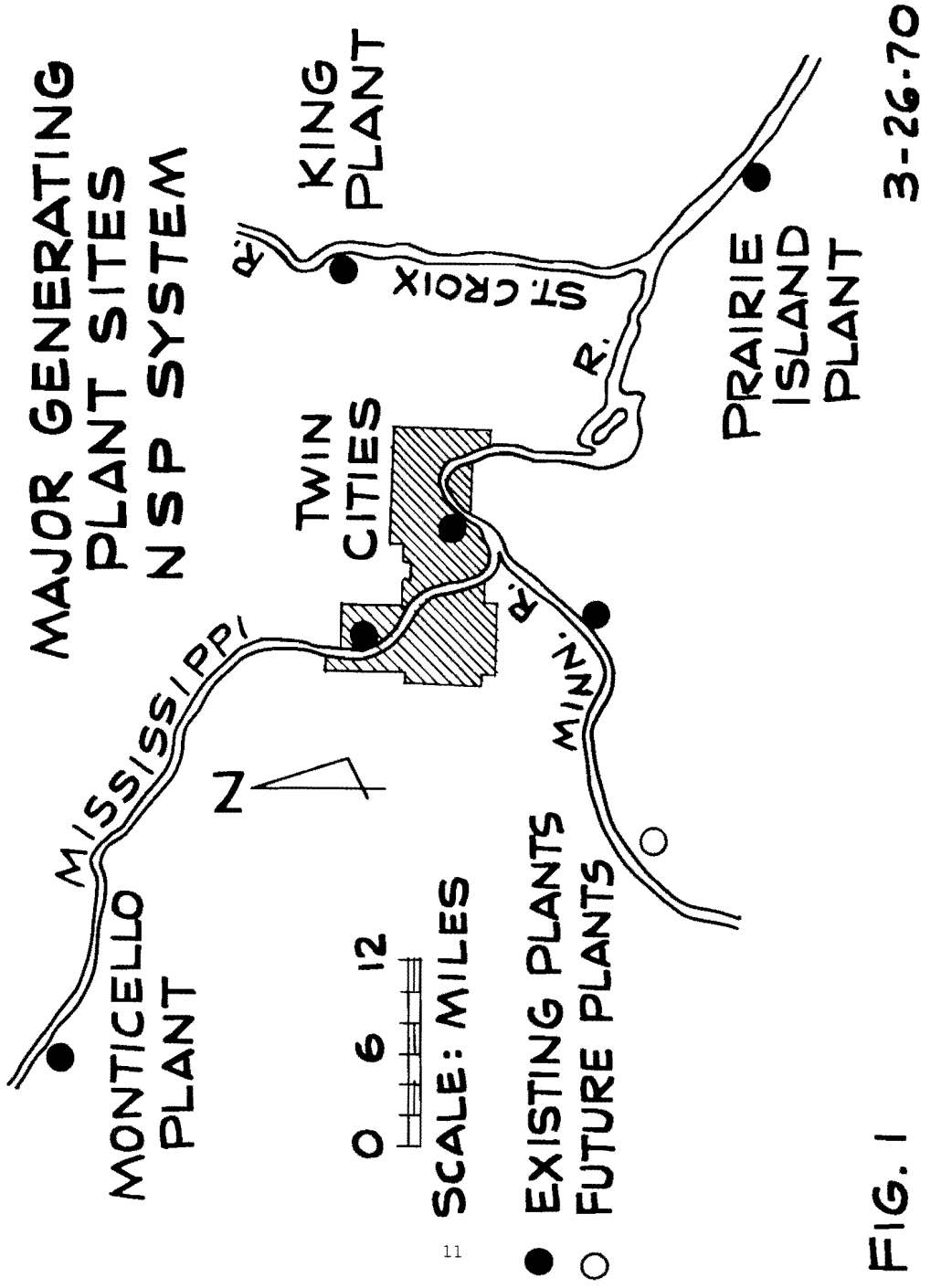


FIG. 1

USUAL ECOLOGICAL PARAMETERS
NSP WATER MONITORING PROGRAM

A. ALGAE

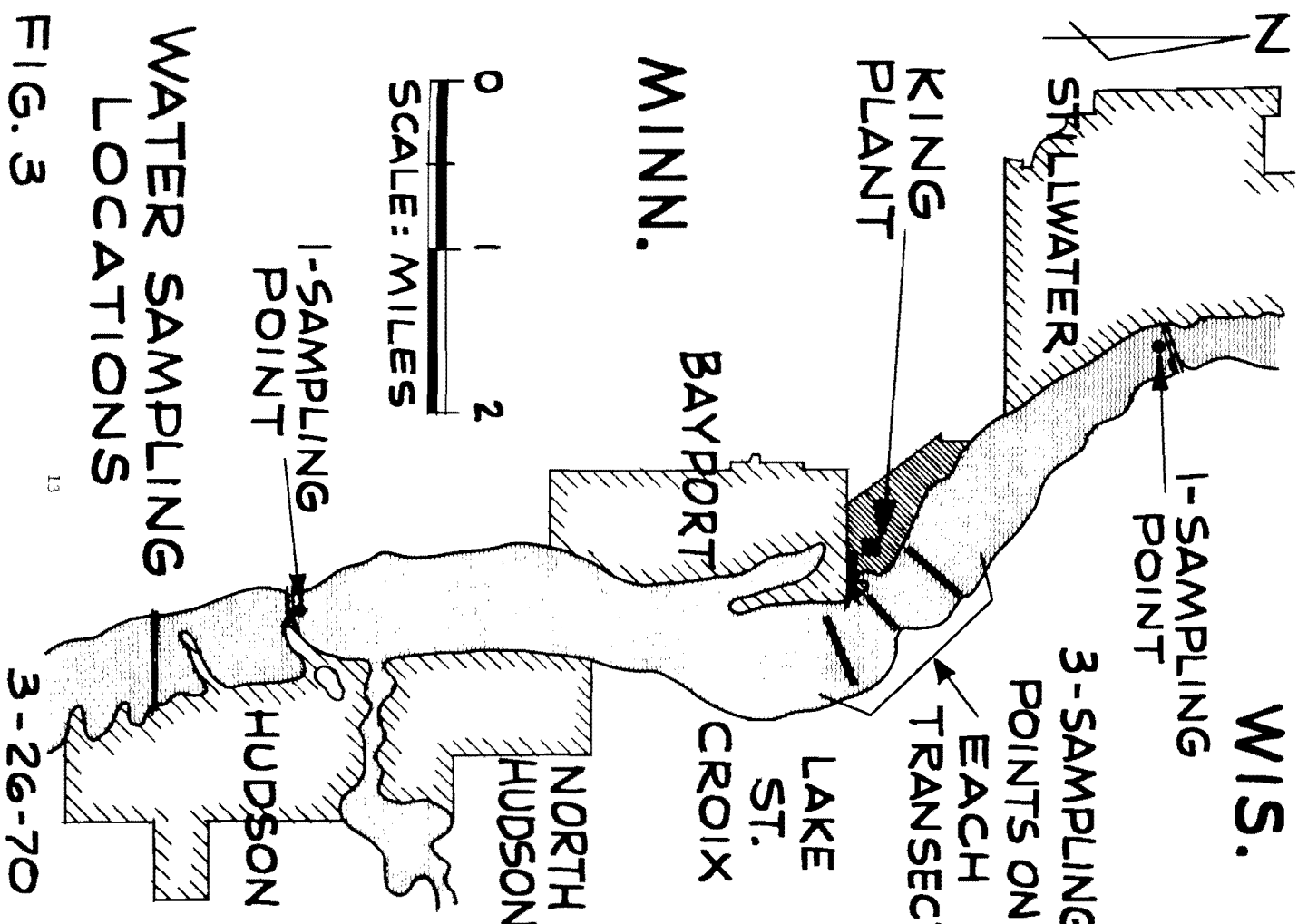
B. INVERTEBRATES

C. FISH

D. WATER QUALITY (PHYSICAL & CHEMICAL) DO, BOD, PH, TEMPERATURE, TURBIDITY, ETC.

12

FIG. 2 3-26-70



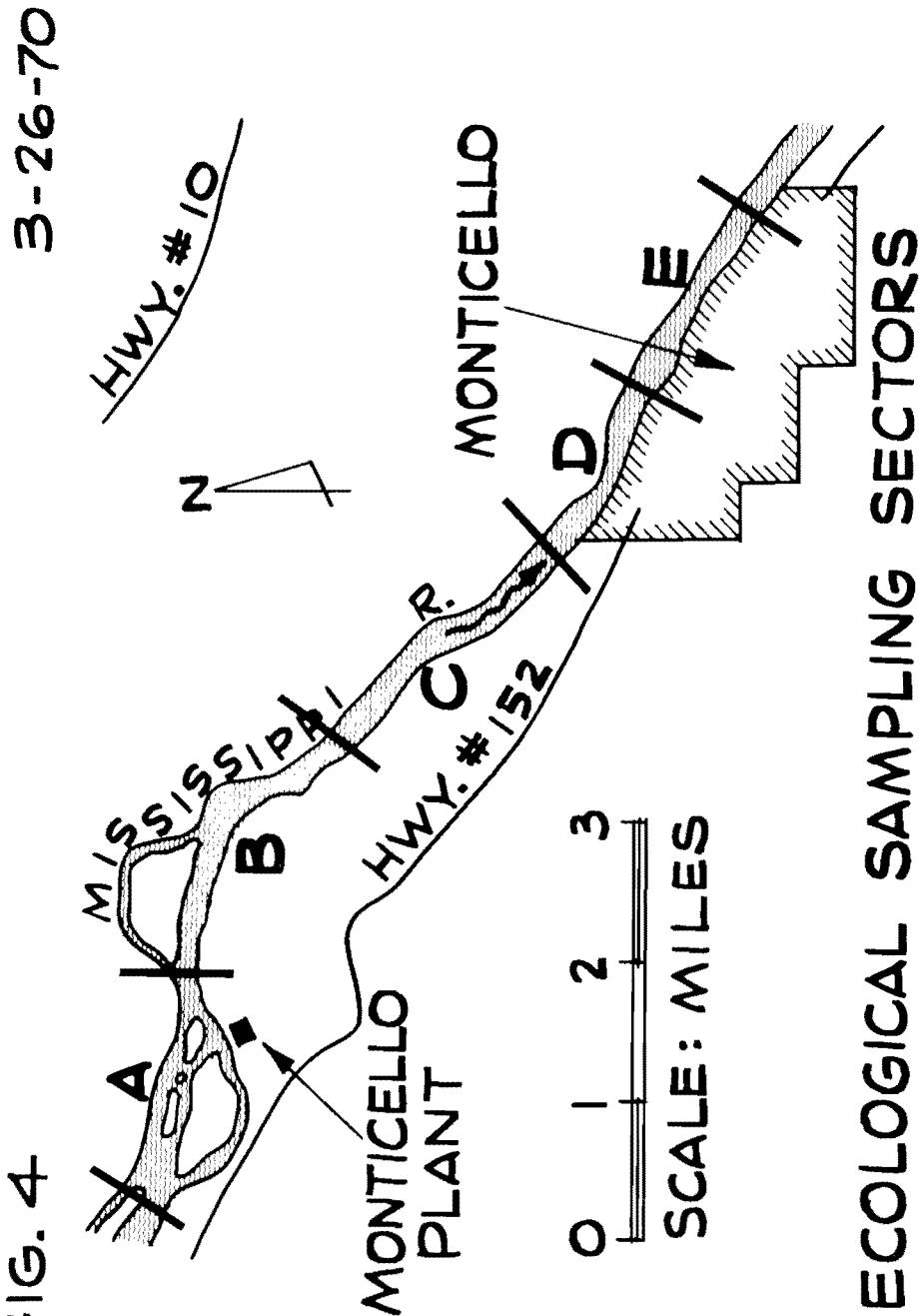


FIG. 4

Cooling towers are provided to limit the temperature of the discharge water to conform with the water quality standards established by the Minnesota Pollution Control Agency. The small quantities of chemical wastes are treated in holding basins and tanks before discharge.

The aquatic portion of the environmental monitoring program at Monticello will cost about $45,000 in 1970. The annual report summarizing the results of the 1968 studies has been issued, and assembly of the annual report for 1969 is in progress. The third major aquatic monitoring program being conducted by NSP in Minnesota is concerned with the Mississippi River near Red Wing, Minnesota, for NSP's Prairie Island Generating Plant. The geographical area covered by the Prairie Island studies is shown in Figure 5. The ecological parameters being measured are the same as for Monticello.

The hydrologic characteristics of the Mississippi at Prairie Island are similar to those of the St. Croix at the King Plant, except that stream flow at Prairie Island is substantially higher. The cooling water flow through each unit of the two-unit Prairie Island Plant is approximately 660 cfs. The first unit is scheduled to placed in commercial operation in 1972, the second unit in 1974. The nominal temperature rise through the condensers is approximately 28°. Cooling towers are provided to process the discharge water to conform to temperature limits established by the Minnesota Pollution Control Agency. The limits for Prairie Island are more restrictive than those required by the general wauter quality standards. Chemical wastes will be treated in holding tanks and released in conformance with water quality standards.

The Prairie Island program was begun in 1969 and is scheduled to reach full operation in the spring of 1970, in order to provide two full years of preoperational data before the first generating unit is placed in operation. The annual expenditure for the Prairie Island program for 1970 is expected to be about $45,000.

The total expenditure for water quality studies which NSP will make in Minnesota during 1970 is estimated to be about $250,000.

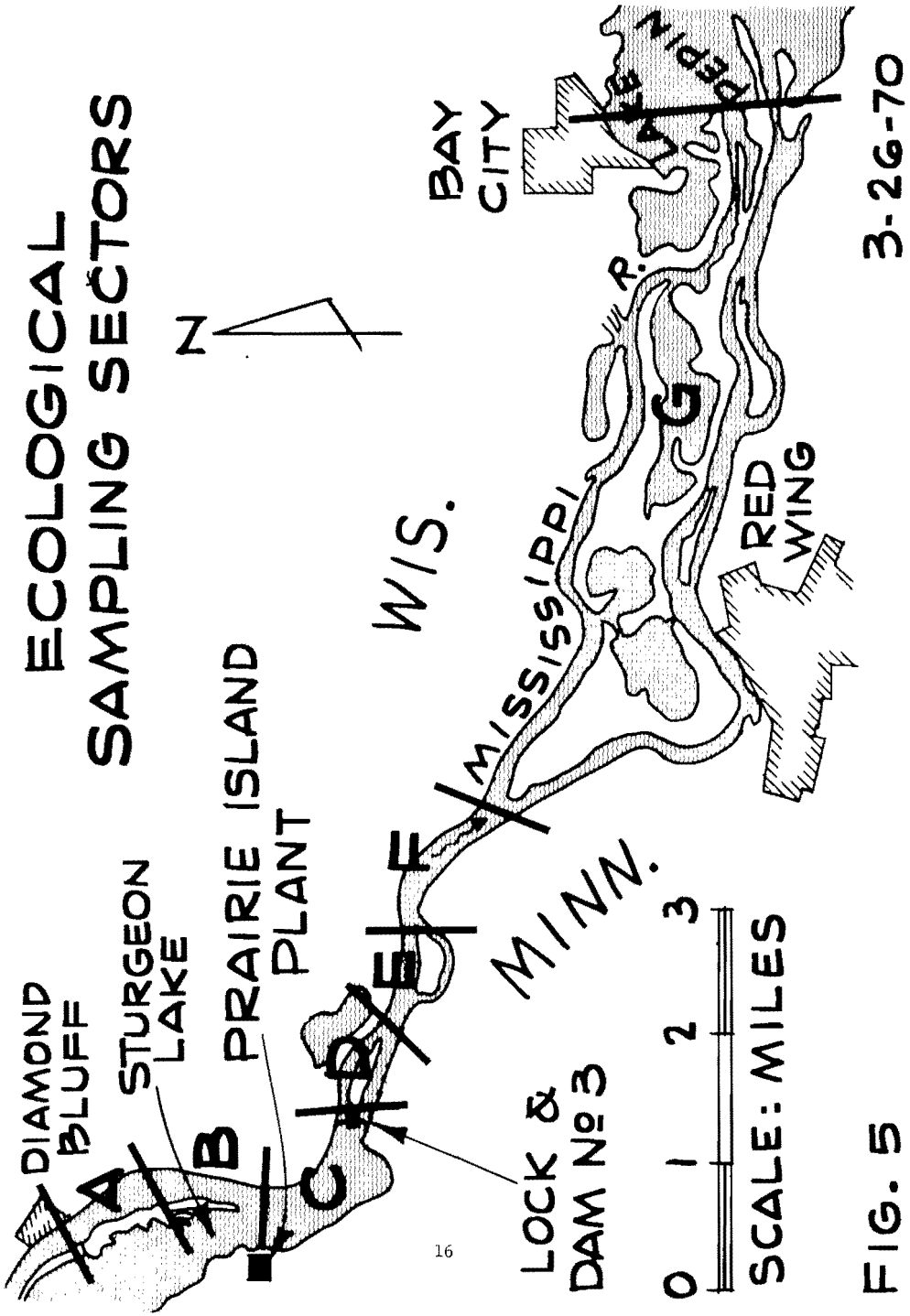


FIG. 5

MINNESOTA AGRICULTRUAL EXPERIMENT STATION

WATER RESOURCES RESEARCH PROGRAM

BY

WILLIAM F. HUEG, JR. 1/

The Minnesota Agricultural Experiment Station has research relationships with most of the agencies represented in this conference today. I am very pleased to have the opportunity to participate in this program and to represent the staff of the Minnesota Agricultural Experiment Station to indicate our interest and involvement in water research. The name "Agricultural Experiment Station" may cause one to wonder why our interest, but there are few things which we do in the research area which do not have some relationship to water - water for growing plants, for livestock, for the forest, for fish and wildlife, and for humans. We also recognize the role that our research plays in other areas such as pesticides, fertilizer, crop plants and animal wastes, soil structure, farm management, public policy and their relationships to water.

The current research effort of the Minnesota Agricultural Experiment Station on water resources involves 17 projects in 6 departments, at 3 branch stations, and an experimental field. The annual budget is $443,446 of which $280,000 comes directly from funds available to the Station. The remaining $164,000 is from grants and contracts with state and federal agencies. The largest single grant and program is that in the fisheries area under the direction of Dr. Lloyd Smith.

Attached is a listing of projects by title and project leader for the 17 projects. A brief description is given as example of a few of these projects. Irrigation studies on water demand and crop response are conducted at the experimental field at Elk River involving 6 departments of the Minnesota Agricultural Experiment Station. Hydrology of watersheds is studied in the Dept. of Agricultural Engineering and in the School of Forestry.

The soil survey and soil classification programs and their relation to lake property as well as use of organic soils as a biological filter are conducted in the Department of Soil Science. The lakeshore survey was conducted under funds from the Minnesota Resources Commission and is in cooperation with several units within the University of Minnesota.

The influence of a major body of water and its fishery on the economic well-being of an area is part of the Lake of the Woods-Rainy Lake Commission study. This study involves not only the biology of the lake but also some of the economic growth factors in the three counties adjancent to Lake of the Woods. Pricing policy on water use is presently not of major concern in Minnesota. However, the competitive demand for water on the part of agriculture, industry, and municipalities makes it essential that we know something about this area so that appropriate decisions can be made

1/ Director, Minnesota Agricultural Experiment Station

Project No.	Title	Project Leader
12-47	Supplemental Irrigation in Minnesota	E.R. Allred
12-55	Hydrology of Small Watersheds	C.L. Larson
14-83	Economic Problems in the Use, Allocation, and Pricing of Water	P.M. Raup
14-92	Economics of the Tourism-Recreation Industry	U. Blank
14-93	An Economic Analysis of the Lake of the Woods-Rainy Lakes Region of Minnesota	J.M. Stam
17-72	Mechanisms of Biological Production in Streams	T.F. Waters
17-75	Investigation of Year Class Formation in Northern Pike	L.L. Smith
17-76	Influence of Water Pollutants and Water Quality on Early Life History and Population Dynamics of Minnesota Fishes.	L.L. Smith
17-77	Investigation of Causes of Population Changes in Red Lakes Commercial Fish Species.	L.L. Smith
17-78	Investigation of Commercial Fish Populations in Western Lake Superior	L.L. Smith
17-79	Lake of the Woods Commercial and Sport Fishing Investigations	L.L. Smith E.G. Heyerdahl
17-80	Dynamic of Separate Intra-Lake Fish Populations	L.L. Smith
19-35	Watershed Values as Affected by Forest Management	A. Mace
21-82	Sand Plain Experimental Field - Operation	P.E. Read
25-15	Soil Survey and Soil Characterization, Minnesota	R.H. Rust H.F. Arneman R.S. Farnham
25-17	Physical, Chemical, and Morphological Studies of Minnesota Organic Soils as Related to Their Classification and Utilization	R.S. Farnham
25-62	Soils Structure: Formation and Alteration	G.R. Blake

into the future. Effects of water quality and food supply on fish populations in streams and lakes is a part of the fisheries biology program.

Some of the studies at the branch stations at Crookston and Morris, as well as the Agricultural Experiment Station, Rosemount, look specifically at some of the animal waste problems. Studies are underway to determine the methods of waste control and their relative costs. Measurements are made on runoff and the amount of organic materials contained in that runoff.

We believe that the State Agricultural Experiment Stations, of which Minnesota is one, are in an excellent position to carry out research on water resources. First, they are located in the field where the problems exist. Each station is able to concentrate on the more serious problems facing the state and can work closely with local interests. In some instances through the regional research approach several stations can join together in attaching problems of water on a regional basis.

Second, most state agricultural experiment stations are associated with universities which can provide the interdisciplinary backup needed for most studies dealing with water resources. Thus, the chemist, microbiologist, engineer, soil, crop and animal scientists, economists, and social scientists, are all available for cooperative attacks on selected problems of water resources. Even the largest of government and private laboratories cannot generally provide the breadth of interdisciplinary expertise available to the "experiment station."

In addition the research programs at the Land Grant Colleges are closely allied with the Cooperative Extension Service which makes it possible to bring the findings of research to the general public. We have enjoyed excellent cooperative relationships not only within the university and the several departments represented on this program today, but with the several state and federal agencies, as well as private agencies concerned with water resources and their development in Minnesota.

WATER RESOURCES RESEARCH CONDUCTED BY MINNESOTA DEPARTMENT OF IRON RANGE RESOURCES AND REHABILITATION

BY

A. M. DE YOANNES 1/

This is not a technical paper. It merely explains how my department, which has invested over $500,000 in water research is involved in the program. On behalf of the IRR&R Commission, which includes 3 Senators (Donald Wright, Minneapolis; Arne Wanvick, Duluth; and Carl Jensen of Sleepy Eye), 3 Representatives (Duane Rappana, Duluth, Chairman; Howard Smith, Crosby; and Raymond Wolcott, Minneapolis) and the Commissioner of Conservation, Jarle Leirfallom, St. Paul, I want to express my sincere appreciation for the invitation to participate in this Conference. I would like also at this time to thank the Water Resources Research Center for the generous recognition given to the IRR&R in WRRC Bulletin 1 of December 1965 for the Department's activities in the interests of water resources research in Minnesota. I submit that I am not qualified to report intelligently on any of the technical results of studies conducted by IRR&R. I appreciate however, that IRR&R funds have been provided to engage qualified agencies to conduct studies in Northeastern Minnesota for the benefit of, and in the best interest of, conservation, private industry, especially the taconite mining industry, and the general public. In my 10 years in this office, I have been convinced of the importance of research in this field and have cooperated, with the advice and consent of my Commission members, with the U. S. Geological Survey, the University of Minnesota through Dr. Rouse Farnham of the Dept. of Soil Science, the Federal Water Pollution Control Administration, U.S. Dept. of the Interior, and the Minnesota Dept. of Conservation, to the extent of funds available at the time of the requests.

Thanks to the generosity of Jeno Paulucci of the Chun King Corporation, the IRR&R owns and operates a 580-acre complex, known as the Wilderness Valley Farms, on the Iron Range. Because of the location of this facility and the trained personnel, and the equipment available for peat research, we have been able to obtain considerable Federal funds for research in wild rice, peat, sod production, forestry, all of which requires considerable information on water resources, resulting in success in our applications for Federal funds for cooperative water projects with agencies and qualified personnel indicated earlier (such as Dr. Farnham, U.S. Geological Survey, personnel, etc.).

Peat Bog Waste Stabilization

Water Supply and Pollution Control Demonstration Project Grant in the sum of $122,635 from March 1, 1967, through Feb. 28, 1969, from the U.S. Dept. of the Interior, Federal Water Pollution Control Administration, known as "Peat Bog Waste Stabilization" project. Reports on this study are available, IRR&R furnished personnel, equipment, & supervision.

1/ Commissioner, Minnesota Department of Iron Range Resources and Rehabilitation

We received this demonstration grant in 1967 (WPD 164-01 (R1-67) from the Federal Water Pollution Control Administration, Department of the Interior, to study the phenomenon by which waste water from a wood processing plant at Floodwood became stabilized after discharge onto an adjancent peat bog. It was thought that peat might be ultimately used for on site water pollution abatement and an explanation of the mechanism involved should be determined. Ruble and Kaple, Inc., Duluth professional consultants in the field of sanitary engineering, performed the first year's study for the Iron Range Resources, State of Minnesota. Both batch type experiments and continuous loading studies were conducted during this period. Laboratory techniques were utilized with the main objectives of reducing the B.O.D. concentration of wood processing effluent. The results of these studies were reported in a first progress report submitted in January 1968. After a review of the progress of the work by FWPCA, a suggestion was made by a Department of Interior official, that sanitary municipal sewage be used after primary treatment along with the wood-products effluent. Also attention was to be directed towards aerobic systems and reduction of phosphate as well as B.O.D. The second year's studies by Ruble and Kaple were thus modified to a trickle-filter system.

During the second year the Iron Range Resources, State of Minnesota, and the Soil Science Dept., University of Minnesota, began cooperative studies in addition to those of Ruble and Kaple utilizing a slightly different approach and different adsorption systems.

Research Development, and Demonstration Grant in the sum of $53,491. ($41,491.00 Federal funds and $12,000.00 IRR&R funds) from April 1, 1969 through March 31, 1970, in cooperation with the U.S. Dept. of the Interior, Federal Water Pollution Control Administration, known as "Treatment of Wastes Using Peat, and Peat in Combination with Soil." The overall objectives of this project are to determine the filtering ability of peat and peat-soil combinations both in the filed and laboratory as adsorptive systems for removing nutrient and organic pollutants in waste waters. 4/1/70-3/31/71 - $87,438 (50% Federal - 50% State).

Several types of filtering systems using peat and peat-soil combinations to renovate waste water are being studied both in the laboratory and the field. The use of vegetative cover on peat was found to increase its filtering capacity as evidenced by phosphate removal. The surface cover seems to function in several ways and results in consistently higher phosphate removal. The lysimeter plots at the city of Virginia sewage plant have been operational since September and were continued into the winter months. These plots appear to be very effective so far and promise to provide maximum information under carefully controlled and semi-automatic basis. Evaluations of the sprinkler systems design is also an objective of these studies because if it is shown to be practical on these lysimeters it could be applied on a large scale field test.

The application of waste water on the natural bog at Wilderness Valley Farms was continued under cold season conditions. It was found the the Penn. State deflector sprinkler performed very well under winter operating condi-

tions. The laboratory cylinder studies using combinations of various peats and peat-soil mixtures will be continued using the facilities of the University of Minnesota Soil Science Dept. These studies have shown very promising results to date and plans are to increase the phosphate removal capacities of these media by additions of specific cations such as hydrogen, iron, calcium and others. The use of chemicals to increase the phosphate adsorption of the peat above that already achieved by physical and microbiological processes is the prime objective of the forthcoming studies in the laboratory. Also the economic feasibility of using peat and soil combinations needs additional study. The possibility of reactivating the peat media so it can be reused to remove phosphate and reduce B.O.D., color and odor of wastewater looks very promising in the preliminary tests performed to date, according to Dr. Farnham. Additional studies, however, are needed to determine the optimal treatment process for reactivation and to evaluate the economics of the process.

Studies over the past two years clearly indicate that peat in combination with soil is a good multipurpose filtering media for wastewater. Not only is phosphorus filtered adequately by reduction in B.O.D. but color and odor removals are possible. Additional studies are needed on additives (chemical) to increase the life of the filtering system and aid in the reactivation process of peat. This will be done if we are funded in April, 1970, only on a limited scale with IRR&R funds, if no federal funds are available.

I'll review briefly some of the U.S. Geological Water Survey area projects.

Gaging Stations

Records of streamflow obtained at five gaging stations, (Embarrass River at Embarrass, Pike River near Embarrass, Stony River near Isabella, Sturgeon River near Chisholm, and Swan River near Warba) have provided valuable information concerning the availability of water resources on the Iron Range. The three stations on Embarrass, Sturgeon and Swan Rivers are classified as primary stations and they are intended to form an integral and important part of the areal hydrologic network of the State. They should be operated permanently to obtain a long-range time sample of the hydrology of the area in which they are located. If a number of primary stations are maintained, the hydrologic network of the State can be considerably expanded on a long-term basis by correlating records from short-term secondary stations with the records from the primary stations.

The increasing emphasis on taconite developments enhances the importance of the continued operation of the gaging stations on the Iron-Range - particularly the primary stations. There have been many requests for stream-flow data collected at the five gaging stations in question. As an example the collected data have been used by Mr. Douglas Barr of Minneapolis in his consulting engineering work for Erie Mining Co., and M.A. Hanna Co. Mr. Barr has stated that he feels the continuation of all five stations is vital for the intelligent planning and development of projects on the Iron Range.

U.S. Geological Water Survey

The Geological Survey's program with the Dept. of Iron Range Resources and Rehabilitation during the biennium July 1, 1964, through June 30, 1966, consisted of completion of data analysis and a report of a project on the ground-water resources of the Hibbing, Minn. area. Funds expended were $3,118.37 in 1965 F.Y. and $7,957.13 in 1966 F.Y. One-half of this amount was from U.S. Geological Survey matching funds. The project was completed and the report written by Gerald Lindholm, geologist, stationed in Grand Rapids, Minn., field office.

The report describes the occurrence and movement of groundwater in the area surrounding Hibbing and indicates areas where it is most feasible to develop additional supplies for municipal growth and industrial purposes. Pumping tests performed on the major water-bearing rock units indicate that relatively large supplies of good quality water are available in selected locations for substantial development. The report indicates that these larger supplies lie along narrow trends away from the central area and that well development might logically follow these trends.

The report provides Hibbing with a comprehensive broad-based water resource report which will serve as a reference for water management. This documented information on water resource availability near Hibbing should materially assist the community in obtaining manufacturing and industrial plants for which a large, high-quality water supply is a requirement.

U.S. Geological Survey suggests that consideration be given to compilation of detailed quantitative reports on the water resources in each of the Iron Range areas where development of large taconite plants will make utilization of all possible sources of supply necessary and where disposal of waste water may create un-anticipated complications. The investigations completed by the Geological Survey on water resources of the Iron Range have been widely used by the iron mining companies and municipalities in developing sources of supply for existing plants, and the information will continue to be used extensively as these plants are expanded.

The completed reports, however, indicate only areas where large quantities of water may be obtained and do not place maximum limitations on the supplies that can be developed. Nor do these reports consider the complex movement of groundwater in the area and the effects both of extensive development and of waste disposal. A detailed analysis of these factors would do much to assure the Iron Range of an orderly economic development in this period of expanding utilization of taconite ores. The Geological Survey completed the report on the availability of ground water in the Grand Rapids area in 1967. The published report, which describes the excellent water supplies available near Grand Rapids is published as a Hydrologic Atlas of the Geological Survey and copies are distributed nationally. During the 1969 F.Y., U.S. Geological Survey collected a very large amount of information on the water-bearing units in separate parts of the Range. In order to make the most useful interpretation of this information, they related these units to each other and made an area-wide interpretation of their water yielding characteristics. The work was simply the completion of the comprehensive report on the glacial geology of the Iron Range with emphasis on the aquifers which was started in 1961 and terminated in 1962 because of a fund shortage.

The study took two years to complete and cost about $30,000.00. The resulting report is of long term value to the economy of the Range for its use in the solution to water problems as well as all planning for the area in which a thorough knowledge of the near surface earth units must be known.

WATER RESOURCES RESEARCH PROGRAMS AT NORTH STAR RESEARCH & DEVELOPMENT INSTITUTE

BY

E. E. ERICKSON 1/

Introduction

North Star Research and Development Institute has been engaged for several years in research directly related to water resources. Our activities began over five years ago with a program to develop a new concept for membranes to desalinate water by reverse osmosis. The conventional reverse osmosis membrane is an anisotropic cellulose acetate film with a thin "active"layer at one surface; the balance of the film is more porous. North Star's concept involved the preparation of "ultrathin" membranes for the "active layer" in reverse osmosis; the more porous support structure was prepared as a separate film. This two-component system permitted the tailoring of each component separately for optimum performance in a given application.

As a result of success in this program, North Star has had several additional research programs in application of its thin film technology to water treatment areas -- three are currently active.

Another area of research for North Star related to water resources is the biological treatment of wastes from food processing plants. For the past 2 and one-half years, North Star has been conducting work on the application of Fungi Imperfecti to food processing waste streams. The program has been successful, and application of the techniques and the organism to other industrial waste streams seem well worth investigation. Experience to date has been limited to a waste stream high in starch content and a waste stream high in protein content.

A third area of related research is one we might call socio-economic impact. An example of this is a recent program to assess the impact of the proposed Blue Earth flood control program on the economic and recreational activities of the region. With this very brief background, I would like to review the status and current activities in these programs at North Star.

Reverse Osmosis

Water Desalination

North Star is currently in the sixth year of its program with the Office of Saline Water to develop new membranes for water desalination. The current phase of this program has as a specific objective the development of a process for applying the ultrathin membrane and a polysulfone support layer to the inside of porous tubes. Ultimately, we hope to apply

1/ Director, Physical Sciences and Engineering Division
North Star Research and Development Institute

the ultrathin membrane technology to the tubular reverse osmosis modules.

The North Star process for making ultrathin membranes involves a solution of the polymer -- primarily cellulose acetate -- on a water surface. The porous support film is prepared by casting the polysulfone solution on a solid surface and quenching in water. We have been successful in the laboratory in preparing polysulfone support in a stainless steel tube, removing it from that tube, and placing it in a porous fiber glass tube. Also, we have been successful in casting cellulose acetate ultrathin membranes inside the tubes. This has been done by placing the cellulose acetate casting solution on the surface of water in the tube while the tube is held in a vertical position. The water is allowed to flow slowly out of the tube, and the ultrathin membrane is deposited on the whetted wall of the tube as the water flows out.

Some of the more recent short-term experiments with 1 percent sodium chloride solutions at a pressure of 800 psi gave water fluxes on the order of 40 to 46 gallon per square foot per day (gfd) and 95 to 97 percent salt rejection. This compares with about 20 gfd and 95 percent rejection with the Eastman anisotropic reverse osmosis membrane that is the best available commercially.

Our process for applying the ultrathin membrane to a tubular system is a major breakthrough. An important advantage of this process, in addition to improved reverse osmosis performance, is the possibility of easily replacing a membrane in situ. The membrane can be dissolved and washed out of the tube by appropriate chemical treatment and replaced without disassembling the system. A large cost savings appears possible by avoiding the conventional disassembly and mechanical membrane replacement operation.

Treatment of Municipal Waste Water

A second current program in reverse osmosis involves the application of North Star's technology to the treatment of municipal waste water. The objective of this program is to determine promising new membrane candidates for waste water application. Criteria for membrane performance are:

-- Water flux should be at least 20 to 30 gfd.
-- At least 50 percent rejection of mineral species is required, and over 90 percent rejection for soluble organics, nitrates, ammonia, and phosphates is desirable.
-- Decline in flux over an extended period of operation should be low.

Polymeric materials being considered for this application include fully substituted mixed esters and ethers of cellulose acetate, xylan acetate, and β-glucan acetate. Membranes are being evaluated with secondary effluent from the Twin Cities treatment plant.

To accomplish the objectives of the program, we are screening our membranes by running short reverse osmosis tests with sodium chloride at an operating pressure of 600 psi. The membranes are prepared by casting as flat sheets on a water surface. Salt rejection below 50 percent or water flux below 20 gfd are generally considered not acceptable. Further reverse osmosis tests are conducted on the more promising membranes using the secondary effluent. Along with water flux, the rejections of total dissolved solids, nitrates, ammonia, soluble organics, and phosphates are observed. Analytical work is carried out with a total carbon analyzer (Beckman) and an atomic absorption spectrophotometer (Techtron). Flux decline of membranes under reverse osmosis conditions is also observed. Decline may be caused by compressing the membrane under pressure and by caking of particulates on the membrane's surface. The latter can be controlled by cleaning. Of the large number of membranes of different polysaccharide derivatives screened to date, some were found to exhibit outstanding reverse osmosis properties and have been selected for further testing and optimization. These membranes vary widely in their performance toward specific separations. However, with secondary effluent as feed, we have obtained water fluxes from 30 to over 60 gfd (compared with 20 gfd for a commercial Eastman membrane), combined with salt rejections from 50 to over 90 percent. Ranges for rejection of other constituents are:

-- 75 to 95 percent for total dissolved solids
-- 40 to 95 percent for nitrate
-- 70 to 95 percent for ammonia
-- 90 to 95 percent for total organic carbon
-- 95 to greater than 99 percent for phosphate

Although these results are for relatively short-term tests, they are tremendously encouraging. We plan to continue our activities by optimizing the membranes and forming them in porous tubes.

Treatment of Metal Finishing Effluents

A third current program is an evaluation of the reverse osmosis process for treating metal finishing waste waters. There are three major goals to be achieved ultimately by such a process.

1. Reclaim the effluents to produce high quality water for reuse.
2. Develop less expensive methods of handling the water pollution problems.
3. Recover metal values presently lost or costly to recover by available methods.

The reverse osmosis performance of a variety of cellulose acetate membranes of the Loeb Sourirajan type (4 mils thick) and ultrathin type (1000 Å or 0.004 mil thick) is being determined using simulated rinse waters from representative plating baths containing nickel, iron, copper, and chromium. The metal concentration in these rinse waters is approximately 100 mg/l. In addition to testing single species metal solutions, mixed metal and high-pH metal cyanide solutions are also being tested. Since the pH of the metal rinse waste waters can vary from less than 2 to greater than 12, the effects of acid or base hydrolysis on the membranes are being determined to select those membranes which will withstand hydrolysis over an extended period of time.

Several reverse osmosis membranes tested to date have been able to reject over 99 percent of the nickel, iron, and copper with water fluxes of 30 gfd. The high metal rejection obtained with these solutions has not been obtained with the chromic acid solution. The best rejection thus far has

been 93 percent, and it has been as low as 26 percent. Membranes tested with metal cyanide solutions at pH 11.0 have all undergone rapid deterioration in less than 40 hours of continuous use. No membranes presently available appear to be able to withstand these severe conditions, so special attention is being given to formulating membranes to withstand hydrolysis at high pH.

Treatment of Food Processing Wastes With Fungi Imperfecti

In applying organisms of the Fungi Imperfecti class to pollution problems, prime objectives have been reduction of the biological oxygen demand to very low levels and to improve the economy of the waste treatment. Among the factors which have entered into the economic considerations are 1) potential sale of the mycelium as a high protein feed, 2) fermentation time requirements, 3) aeration requirements, 4) cost of added nutrients, 5) fermentation reliability, and 6) harvesting costs. All of these criteria have been met on a laboratory scale. The status of present understanding may be summarized as follows:

1. BOD reduction in continuous fermentation of corn wastes has been excellent. Typical of results are a reduction from a BOD of about 4,000 ppm in the feed to less than 50 in the effluent, or a reduction of about 99 percent. The corresponding COD reduction is from about 5,000 to 200. BOD reductions of soy wastes have been less dramatic, but even so, have been over 97 percent.
2. The fermentation cycle has been satisfactorily short. The retention time necessary to obtain complete digestion has been in the neighborhood of 20 hours. We expect that it may be possible to reduce this time even further.
3. Aeration requirements have been particularly encouraging. One pound of dissolved oxygen has been used per seven pounds of BOD removed. The explanation of this low aeration requirement lies in the incorporation of a great part of the nutrient into the mycelium.
4. Maintaining Fungi Imperfecti as a dominant organism has proved feasible. This is in spite of the fact that there has been no sterilization of the waste stream before introducing it into the fermentation.
5. The fungi are macroscopic in size and can be removed by gross filtration. This was a primary reason for choosing Fungi Imperfecti for the investigation.
6. The utility of mycelium as an animal food appear promising. A protein content in the neighborhood of 50 percent is attainable. The amino acid composition is reasonably well balanced and compares favorably with that of the protein from Opaque-2 corn.

The process is presently being tried on a 10,000 gallon scale on corn wastes. About six weeks of operation were maintained last season. The fungi established themselves and were maintained satisfactorily. Because of the low temperature late in the season, BOD removal was less complete than in the laboratory.

Socioeconomic Impact

In addition to the technical aspects already discussed, North Star has recently worked on the socioeconomic aspects of water resources development to assess the social and economic impact of the proposed Blue Earth Dam and Reservoir. This project was conducted for the U.S. Army Corps of Engineers to provide an independent and objective viewpoint with which their own studies could be compared. Although our report limited itself to the effects of the water program on the immediate vicinity of the dam and reservoir, its coverage in terms of subject matter was wide. It dealt not only with the ecological and recreational effects on the area, but also with other economic aspects of both the construction and post-construction period. As in most research dealing with what is essentially a water resources problem, there were tangential aspects which required consideration as well. Among these were transportation, education, and pollution impact.

The study showed, for example, that there was a much greater awareness of environmental and ecological effects than we had expected. On the other hand, the impact on the tax base was found to be far less than anticipated by either the proponents or opponents of the project.

Conclusion

The research that I have described indicates North Star's broad interest in the area of water resources research. With these programs, and others still in the planning stage, North Star will play an important role in water research in this region of the country.

CURRENT RESEARCH AT THE LIMNOLOGICAL RESEARCH CENTER

BY

R. O. MEGARD 1/

The Limnological Research Center was established with funds provided by the Hill Family Foundation in 1963. Since that time the Center has provided a focal point for limnological research by staff and graduate students in the departments of Ecology, Geology, and Botany. During the last year, 8 faculty, 5 post-doctoral students, and 16 undergraduate students were affiliated in one way or another with the Limnological Research Center. Financial support for projects is currently derived from the Minnesota Resources Commission, the National Science Foundation, Federal Water Pollution Control Agency, the Atomic Energy Commission and the Office of Water Resources Research. Research activities involved both neo-limnology, primarily the biology and chemistry of lake waters, and paleolimnology, which is the study of lake sediments.

In 1965 a mobile laboratory was constructed that has been used to study the abundance and daily growth rates of algae in 20 lakes in different parts of the state. Lakes in different regions of Minnesota differ markedly depending on the origin of the basins, regional geology and climate, and the type of vegetation in the watershed. The facilities of the mobile laboratory have been used to determine the effects of these variables on the abundance and daily growth rates of algae and also to follow the seasonal changes in water chemistry. The field work for this project has been completed and it provides a yardstick for evaluating the fertility of lake water in biological terms. The algal productivity of most lakes in northeastern Minnesota is usually much lower than in lakes elsewhere, but the productivity of lakes that are enriched with sewage effluents is much higher than in lakes that are not so enriched, even in northeastern Minnesota.

We have undertaken an intensive analysis of the abundance and growth rates of algae in two lakes both to obtain information about algal ecology and to develop procedures for measuring and diagnosing lake pollution. The two lakes in question are Lake Minnetonka near Minneapolis, and Shagawa Lake, near Ely, both of which are enriched by sewage effluents. The Federal Water Pollution Control Administration plans to build an advanced sewage treatment plant at Ely that will remove virtually all the phosphorus from the Ely municipal sewage effluents. The measurements of algal abundance and growth rates in Shagawa Lake will provide a baseline for evaluating the effectiveness of phosphorus removal. We also hope to identify the critical nutrients that control algal growth in Shagawa Lake so that this information may be used for designing and operating the plant.

At Lake Minnetonka we are cooperating with the State Pollution Control Agency and two Engineering firms to develop a comprehensive nutrient abatement program for the watershed. Phosphorus appears to be the critical nutrient that controls algal growth in Lake Minnetonka during the summer, when the algae are most abundant. The lake should recover very quickly if the phosphorus influx can be controlled, because phosphorus is deposited in the sediments very soon after it enters the lake. Most of the phosphorus is permanently locked into the sediments after it is deposited so that the sediments are a very effective nutrient trap. Some of the phosphorus is released from the sediments during summer and winter stratification and during the autumn turnover, but it is soon re-deposited. The net rate of phosphorus deposition in the sediments is about 5 lbs/acre/year.

In addition to these field studies, Joseph Shapiro is conducting several laboratory studies of water chemistry. He is studying the effects of the so-called humic substances in water on the availability of nutrients for algae. He has also developed new methods for analysing for phosphorus in water, primarily to devise phosphorus analyses that are more meaningful ecologically. He and a student are beginning a project that involves comparing the rates of phosphorus uptake by different kinds of algae under different environmental conditions. They are attempting to determine whether or not different rates of uptake are responsible for the seasonal succession of algae and single-species algal blooms. Another project involves a study of the different chemical states of phosphorus in lake sediments. The objective is to determine which phosphorus compounds are released from sediments and the conditions under which they are released.

Another project is being undertaken by Robert Carlson at Lake Minnetonka to determine whether or not the blue-green algae that produce dense algal blooms are eaten by zooplankton. An important justification for this study is to determine if nuisance blooms of blue-green algae develop because the animals feed on other kinds of algae but not on the blue-greens.

A visiting scientist from Czechoslovakia, Dragica Matulova, has been using laboratory cultures of algae as bioassays to define the extent of pollution in a variety of lakes in various parts of the state. She has also applied several other biological assessments of pollution that are widely used in Europe to Minnesota waters.

Several students of Dr. A.J. Brook in the Ecology Department are studying the ecology of natural algal populations. Several studies of populations that are stratified at restricted depths in some lakes in Itasca State Park are in progress. Another project involves a study of the morphology, life history, and nutrition of Aphanizomenon, one of the most common nuisance algae. In another project, the abundance and distribution of attached algae, primarily diatoms, in the St. Croix and Mississippi Rivers are being studied to evaluate the effects of heated effluents from electrical generating plants.

Dr. Eville Gorham in the Botany Department is using radioactive tritium from atmospheric fallout as an indicator of the movement of water through bog peats and lake sediments. Dr. Gorham and Jon Sanger have also been studying the occurrence of plant pigments and their degradation products in peats and lake sediments. They are particularly interested in isolating and identifying the various plant pigments in sediments and relating the pigment fractions to the productivity of the environments in which they originated. Dr.

1/ Assistant Professor, Limnological Research Center, University of Minn.

Gorham and Walter Dean, now at Syracuse University, have also studied the chemistry of lake water and sediments in different geographic regions of Minnesota. This will provide a framework for interpreting the results of the regional survey of lake productivity that was discussed earlier.

Dr. Herbert Wright and his students are carrying out several studies of lake sediments underway in Minnesota. A project by Wright and Mel Whiteside involves studying short sediment cores to see whether or not the onset of lake pollution can be detected by studying fossil Cladocera, which live on rooted aquatic plants and are well-preserved as fossils in sediments. In other projects at Elk Lake in Itasca Park and Lake of the Clouds in the Superior National Forest, laminated lake sediments are being studied. At Elk Lake, fossil ostracods, diatoms, mollusks, and chironomids have been analysed in order to work out the ecological history of the lake with respect to climatic change and water level fluctuations during the last 10,000-12,000 years. There are about 9,500 laminations in the sediments of Lake of the Clouds. Radiocarbon dates indicate that these are probably annual so that the sediments provide us with an absolute time scale for the Superior National Forest which can be used to determine the climatic and vegetational changes that have occurred since the last glaciation in that region.

I have attempted to summarize the current research of the faculty and students associated with the Limnological Research Center that pertain to Minnesota water resources. I have not described projects involving pollen analyses and vegetational history that are also underway. Some of these involve Minnesota but others involve other parts of the United States and other countries.

RESEARCH ACTIVITIES OF THE DEPARTMENT OF ENTOMOLOGY, FISHERIES & WILDLIFE IN WATER RESOURCES

BY

LLOYD L. SMITH 1/

Areas of Research

At the present time fishery biologists are concerned primarily with fish populations as potential food sources and as a base for sport fishing recreation. In addition to this, a second major area of concern is, problems of water quality as they relate to fish production and maintenance of an aesthetically satisfactory aquatic environment.

Within this framework, the Dept. of Entomology, Fisheries and Wildlife has established its research program. The program consists of three major segments: First, fishery population dynamics which involves the study of ecological response of exploited fish populations and, the effect of harvest rates on productivity of fish population. The second major area of investigation is on water quality and its relationship to fish production and water quality standards. A third area is the energetics of production of stream fish and the transfer energy from lower trophic levels to fish and the environmental conditions which permit maximum efficiency of this transfer.

Water Quality Studies

Water quality studies have been directed primarily to the effect of sub-acute levels of toxicants on all phases of fish life history. Repeated observations have indicated that acute toxicity tests (TL_m) are of limited value for the setting of stream standards, since they do not indicate the subtle responses of reproduction, growth, and long-term survival. Laboratory studies have been designed to carry fish over long periods of time, at very low levels of toxicants to determine the subtle responses.

Five species of fish are now under test to determine fecundity, growth rate, food acceptance and utilization, and survival of eggs and fry at low concentrations of H_2S and other materials. In addition to these studies, an attempt is being made to develop a "standard fish" for bioassay purposes. To this end, an inbred strain of goldfish is being carefully tested to determine its variability, its repeatability of response, and other factors which would permit recommendation to other laboratories for comparison with local fishes. This particular strain is highly desirable if tests show it to be a successful test animal because it is available in commercial quantities and can be acquired by other laboratories at any time.

1/ Professor, Department of Entomology, Fisheries and Wildlife, University of Minnesota

Results of water quality studies to date show that extremely low levels of toxicants may be deleterious to some life history stage in a number of species. Levels as low as 1/40th or 1/50th of the 96 hour median tolerance limits (a few parts per billion) may be detrimental. In the case of H_2S, these levels are lower than those often found in a state of nature. Therefore, important ecological relationships heretofore unexplored are being revealed. These studies are especially important if we are to attempt to meet Federal water quality objectives of "no degradation of the environment." An important result showing up in studies is the change in behavior especially with relationship to spawning which, although apparently not physiologically detrimental, may alter the fishes ability to reproduce successfully. One other very interesting result is that extremely low levels may actually stimulate the certain physiological functions of the fish, and result in higher growth rate and greater activity.

Fishery Dynamics

The study of fish population with the attempt to understand the ecological responses which govern production are essentially field programs but may be brought into the laboratory for confirmation under experimental conditions. An important facet of these studies is the determiniation of total production under different patterns of commercial and sport fishing exploitation.

One of our principal studies in progress is the fishery dynamics study of Lake of the Woods commercial and sport fishes. Included in this study are the walleye, tullibee, sauger, and the burbot. This last species has a potentially large production for human consumption which has as yet been untapped. To the present time it has been used primarily for mink food. Inasmuch as there appears to be a future for this species, detailed life history studies are being conducted.

The Lake of the Woods fishery study is being meshed with an economic study of the area conducted by the Dept. of Agricultural Economics. The combined study integrates fishery production, agriculture, forestry, tourist industry, and mink farming. An entire economic regional analysis integrating the fishery will be forthcoming. The study is especially significant because it constitutes one of the first regional studies where fishery has been incorporated into other economic values of the region. A second dynamics study has been conducted in western Lake Superior where the causes of decline in herring population during recent years have been intensely studied. It has been demonstrated that this important commercial species has suffered from competition from the smelt and chub and that restoration of herring populations will probably depend on much heavier utilization of the smelt populations to reduce their numbers. A second aspect of this study has been a general assessment of the food and predator relationships of all western Lake Superior fishes to determine the ecological relationships existing among them. These studies have as a basic objective restoration of possible commercial species in western Lake Superior.

Fishery environmental studies

The third major area of investigation concerns the dynamics of the fishery environment with special reference to invertebrates. Since the

maintenance of the environment and its basic food producing capacity is an essential for maximum fish production, these studies are considered to be highly important. Specifically the research seeks to determine the quantitative aspects of the population ecology of invertebrate animals inhabiting running waters. It includes study of production rates; growth and mortality rates; rates of change in population density; behavior and dispersal rates; and the effect of environmental factors upon them. The emphasis on invertebrates is significant, because it is this group that constitutes the energy link between plants and fishes and that is the most sensitive to the quality of the aquatic habitat and to environmental disturbances such as pollution, and foods.

WATER RESOURCES RESEARCH ACTIVITIES OF DEPARTMENT OF CIVIL ENGINEERING & HYDRAULICS

BY

EDWARD SILBERMAN 1/

I want to talk about the water resources related research of the faculty of the Dept. of Civil Engineering and Hydraulics. Our research activities are concerned with hydrology, hydraulic engineering and sanitary engineering. To define the terms somewhat loosely, I suppose you could call hydrology the study of the occurrence of water in nature and the materials that water carries and deposits. Hydraulic engineering is the study of the means by which man can change the natural processes governing the flow of water and the materials water carries and deposits. Sanitary engineering is the study of the means by which man can control the quality of the water.

The hydrology and hydraulic engineering research is largely conducted at the St. Anthony Falls Hydraulic Laboratory which has a substantial staff in addition to the Professors in the Dept. of Civl Engineering and Hydraulics who are engaged in research projects. The sanitary engineering research is conducted in separate laboratories on the Minneapolis Campus of the University. The St. Anthony Falls Hydraulic Laboratory is off-Campus.

Our research has to be supported by income from outside the University, either as government agency or as private agency funds projects. At St. Anthony Falls Hydraulic laboratory we receive considerable support from private agencies as well as from various governmental agencies.

I will now describe two hydrology projects. One project was supported by the Water Resources Research Center and was concerned with the hydrology of Minnesota river watersheds. Professor Bowers was responsible for this project. The objective of the study was to relate runoff to the rainfall or snow as it may be.

Another hydrology research project involved the making of a movie, with support from the Department of Conservation, on the 1965 flood in the Minnesota River Valley. The movie was intended to be educational as well as a permanent record of what had happened.

Both those of us at the St. Anthony Falls Hydraulic Laboratory and those in the Sanitary Engineering Division have conducted a good deal of research over the years for the Minneapolis-St. Paul Sanitary District with support from the District and the FWPCA. One of the interesting studies we did was concerned with the routing of sewerage through interceptor sewers during storms. The sanitary engineering faculty has worked on various biological and sanitary processes pilot plants for the Sanitary District over the last fifteen years. At the laboratory we have worked with the Sanitary District on the improvement of their grit chambers. These are chambers in which the sewerage coming into the treatment plant is

1/ Director, St. Anthony Falls Hydraulic Laboratory

screened to get large sediments out of the waste.

A good deal of our research at the Laboratory deals with hydraulic engineering structures. Not very many of these structures are built in Minnesota. Many of the structures have been constructed in remote places in the world, not only in the U.S.A. Structure research involves dams, spillways, and breakwaters.

A recent project was sponsored by the Bethlehem Steel Company. They had been ordered to stop dumping slag from their plants into Lake Erie. They had proposed to build a dike around an area in the lake in order to enclose the slag that is dumped so it would not get into the rest of the lake. We conducted a study to determine how the currents in Lake Erie would be affected and how waves would be affected by the presence of the dike. Would they have more sand transport or less sand transport over nearby municipal water intakes which are located in Lake Erie?

One project we did in Minnesota was for the Highway Department. It concerned design features of a breakway which was to protect the freeway running along the water front in Duluth. The Highway Department has water resources problems and we occasionally do research work for them involving culverts and bridges. Our Laboratory also made a comprehensive model of the Mississippi River navigation project in North Minneapolis.

We were also asked by NSP to study the temperature distribution which might occur in Lake St. Croix as a result of their proposed Allen S. King Plant. The study involved a model. Thermal pollution studies have been supported both by the FWPCA and the Atomic Energy Commission. We are studying the dispersion of heat in lakes. There are two aspects of the research, one is what happens to the warm water as it is ejected into the lake and the other what happens as the warm water layers flow along over the cooler water.

Donald Mount, this morning talked about their fish rearing ponds in Monticello that they are going to build, using the waste warm water from the power plant there. We have been engaged in research with the Federal Water Pollution Control Agency sponsorship to help Donald design the fish rearing ponds, so that they can regulate the temperatures of the water in the ponds by using the warm power plant water discharge and cold groundwater as necessary.

We carry on continuously a very large program in connection with sediment transport. Sampling methods, transport properties of fluids under different flow conditions, erosion of flow, are studied. We have project support from U.S.G.S. for continuous electronic sampling of sediment concentration. We also have a cooperative research group called the interagency project in sediment transport which is staffed by people from U.S.G.S. and the U.S. Army Corps of Engineers Civil Works program who conduct research in sediment problems.

We will soon begin a study of systems analysis applied to large watersheds. This will be supported by the Water Resources Research Center. Our

sanitary engineering division has just completed a seven-year study under Public Health Service support of the travel and transformation of nitrogen compounds in soils and they have also been studying nitrogen removal from sewerage.

U.S.G.S. WATER RESOURCES RESEARCH ACTIVITIES

BY

CHARLES R. COLLIER 1/

The Water Resources Division, U.S. Geological Survey is deeply concerned with water-related research in the appraisal and accounting of the Nation's water resources. Today's emphasis on environmental quality, and the ever-increasing demands on our water resources require a thorough understanding of the water system and man's impact on that system. This can be accomplished only through the efforts of basic and applied research.

The Survey's principal centers for research are located at Denver, Colorado; Menlo Park, California; and Washington, D.C. However, research activities, particularly in the category of applied research, are an integral part of many projects conducted in the districts which are organized in general along state lines. Time does not allow a detailed discussion of each active water resources research project being conducted by the Minnesota district. Several of the projects are familiar to many of you, and I shall mention them only briefly today. Others are relatively new projects and will be described in greater detail.

The U.S.G.S. is presently engaged in a nationwide study to evaluate the existing streamflow data program of each district and to examine ways in which it may be improved. The principal elements in the study are 1) establishing the objective and goals of the program, 2) examining and analyzing all available data to determine which of the goals have been met, and 4) identifying elements that should be included in the future program.

The goals of the streamflow data program are established by spelling out in specific terms exactly what types of information the program is expected to produce as the final product. Streamflow data needs are grouped into four categories: data for current use, data for planning and design, data to define long-term trends, and data on the stream environment.

Data for current use refers to data being used currently for management, assessment, surveillance, warning, legal, or research purposes. The historical record and sequential occurrences of hydrological events are important for this use. This part of the program is not subject to design using scientific sampling theories, because the location of the stations, the time frames of reporting, and the periods of operation are specified by the users of the data.

Data for planning and design consist of statistical descriptions of streamflow to be expected in the future. This is information such as the mean annual or monthly flows; flood peaks or volumes expected every 10, 25, or 50 years; low flows, for varying durations, expected every 10 or 20 years; descriptions of streamflow variability, etc. Such information must be available wherever desired, and is therefore not restricted to gaging stations alone, but must be available for any point on a stream;

1/ District Chief, U.S. Geological Survey

it must be available for streamflow under either natural or regulated conditions. The necessity for furnishing such data shows why the streamflow data program is not simply one of data collection, but must include analytical studies for extension and generalization of information.

Definition of the flow characteristics must be by some process of regionalization. On the basis of available data, the relation between each statistical flow characteristic and variables that describe the geometry and climate of the basins is being determined by multiple regression. This requires computer storage of all pertient streamflow data, computation of a number of basin characteristics, and definition of statistical flow characteristics and regression relations by the computer. Data for 93 Minnesota gaging stations are being used in the analysis. Basin characteristics being used are drainage area, main channel slope, stream length, rainfall intensity, snowfall and annual precipitation, surface storage percentage of area in forest, mean basin elevation and soil index.

The need for data to define long-term trends can be met by operating indefinitely a representative sample of gaging stations on natural streams in each region of the country. To achieve good geographical coverage it is planned that two such stations be operated primarily for this purpose in each of the 207 planning subregions of the U.S. as tentatively identified by the Water Resources Council. Minnesota contains parts or all of 11 subregions. The stations will be selected from the existing network.

Environmental data include a wide variety of water-related information other than stream discharge, such as channel and basin characteristics, land use, time of travel, and properties of aquifers connected to the stream. These data are useful in hydrologic studies and in planning, designing, and operating systems for controlling water or pollution. The collection and publication of such data will be a part of the future investigational program of the Geological Survey.

The results of the evaluation will be used in planning and guiding the future streamflow data program. Less productive elements in the present program can be weeded out, and the effort devoted to data of higher priority. The program will provide for continuous interaction between data collection and analysis to gain a better understanding of the hydrologic system. The evaluation, and the statistical data available from it, will be a basis for more detailed studies and reports on specific streamflow characteristics such as regional flood magnitude and frequency, low-flow frequency, flow duration, and the relationships of streamflow to basin characteristics.

A study of the flood-frequency characteristics of small watersheds throughout Minnesota was begun in 1959 in cooperation with the Minnesota Dept. of Highways. Annual flood peak discharges are determined at 128 sites equipped with cres-stage gages. Continuous records of stage are obtained at 10 sites to provide hydrographs of storm events. The flood frequency data will be regionalized and correlated with several watershed characteristics.

An appraisal of the surface and ground-water resources is being made

for each of Minnesota's 39 watershed units in cooperation with the Minnesota Dept. of Conservation, Div. of Waters, Soils, and Minerals. Hydrologic Atlases are now being published for 12 watersheds, 5 atlases are in press, and the work is in various stages of completion for 9 watersheds.

Besides providing general information on water availability and water quality, these watershed studies are yielding considerable insight to the water system of the State. One of the principal efforts of an applied research nature concerns the definition of ground-water flow systems. A knowledge of ground-water flow systems is important in mapping recharge and disharge areas of the ground-water system, establishing the ground-water relationship to streams, determining the distribution of grounwater quality types, and estimating the flow paths of pollutants that are placed on the land surface or injected into the ground. For example, a hydrologic section in the Yellow Medicine watershed shows that water moves into the ground-water system on the top of the Coteau des Prairies highland and discharges at the base of the steep slope coming off the highland. It shows ultimate discharge into the Minnesota River, but also shows areas of recharge or movement away from the water table and discharge or movement towards the water table across the Minnesota River valley.

The relationship of groundwater to surface water is stressed in the watershed program. The streamflows are rather low, decreasing in areas where water moves into the ground-water system and increasing where groundwater is discharge d to the stream. This can be illustrated by a map of water-table contours and a flow diagram made from a series of streamflow measurements made during the period Sept. 19-21, 1967 in the Wild Rice River watershed. An increase of 10 cfs (cubic feet per second) in the headwaters occurred in the area where the Wild Rice River flows across a deposit of outwash sand and gravel. Little increase in streamflow occurred from there to about the middle of the watershed. Water-table contours indicated movement to the river in this reach but the soil in the area is fairly tight glacial till which yielded little water to the stream. In the area of sandy beach ridges, which were formed by Glacial Lake Agassiz, the Wild Rice River discharge increased about 6 cfs, and flow in the Sand Hill River increased from less than 1 to about 12 cfs. Little to no pick-up in streamflow occurred in any of the rivers where they flow across the relatively impermeable glacial lake clays in the Red River valley lowland.

Mapping of types of ground-water quality is also stressed in the watershed program. This involves systematic collection and chemical analyses of groundwater samples from a watershed area. The analyses are classified according to water types and the result plotted on maps and cross-sections or fence diagrams to show the areal and vertical distribution of water quality. The distribution of water types are generally related to the geologic environment and the groundwater flow patterns.

Other projects in our areal studies program include determining the availability of ground water for irrigation in the sandy-soil regions of Minnesota. For most of these studies electric analog models have been built to aid in the analysis of data.

Several local, State, and Federal agencies are cooperating in a study of the improvement of water quality of Lake Sallie near Detroit Lakes by two methods: 1) removal of nutrients by filtration of sewage plant effluent through peat, and 2) by removal of nutrients through harvesting of aquatic weeds. The Survey's responsibility in this project is to determine the water budget of the lake. All surface inflows and outflow are measured. A digital model of the ground-water system is being prepared to help define the flow patterns and determine the contribution to the lake. Measurement of both water discharge and water quality are obtained on the stream both upstream and downstream from the interagency study area.

A project is nearing completion that involves quantitative geohydrologic mapping techniques to define and describe aquifers in the Mesabi Iron Range area. This work is in cooperation with the Dept. of Iron Range Resources and Rehabilitation. Statistical analyses of geologic data are being used to map the location of aquifers and to describe the internal facies relationships of individual aquifer units. This information is then used to show the variability of the aquifers and to identify the parts of the aquifers where highest yields to wells could be expected.

There is strong and growing interest in the use of aquifers for the subsurface storage of fresh water and for disposal of wastes. The greater interest and need lie in the use of aquifer storage capacity for recharge of fresh water to bolster dwindling supplies, for maintaining water levels within economical reach of pumps, and for leveling out fluctuations of water availability from time to time and place to place.

In 1970 the Geological Survey substantially accelerated a research program in this field, which will identify, develop, and demonstrate artificial-recharge techniques that offer the best possibilities in relation to various hydrogeologic situations. Of particular interest to those parts of the country in which storage of surplus surface water offers promise for increasing water supply are sand and gravel aquifers and fissured and cavernous rocks such as limestone and basalt, which have been relatively neglected in studies to date. Accordingly, three pilot areas, representative of different hydrogeologic situations, have been selected for experimentation and research in artificial recharge techniques.

The areas selected for the program are the stratified rock environment of the High Plains in Texas, the sand and gravel units of Long Island, New York, and the fissured carbonate rock in the Twin Cities area of Minnesota. The hydrologic and geologic data being obtained in cooperation with the Twin Cities Metropolitan Council was a major factor in the selection of this area for the recharge research.

The recharge project is just getting underway in the Twin Cities area. The plans for the first phase of the project are completed and a site in West St. Paul has been selected. Test drilling and hydrologic analyses of the cores will begin this spring. A site was chosen outside of the large pumping centers to minimize the effects of uncontrolled pumping. However, because artificial recharge will most probably be performed in the large pumping centers, the experiment is being conducted in an area geologically similar to the area of heavy pumping. The injection well will be finished in the Prairie du Chien dolomite. By injecting into the fractured dolomite it is anticipated that large amounts of water will quickly disperse along fractures and solution channels over a relatively large area and then recharge the underlying Jordan sandstone.

The purpose of the experiment is to test and demonstrate the hydrologic feasibility of recharging fractured carbonate rocks. Experiments will be conducted to examine problems common to recharge operations such as well design, construction, and efficiency; effects of various injection rates; and air entrainment.

Subsequent phases of the study may include comparisons with injection directly into the Jordan sandstone, injection into both rock units simultaneously, recharge of the sandstone through its contact with the glacial drift along buried valleys, and the effects of temperature differences and chemical character of the recharge water on the recharge process.

Information gained from these studies will point the way to successful recharge techniques in other aquifers in similar geologic environments. The program envisions a continuing effort to apply these techniques to additional aquifer situations as local management plans move from the conceptual to the operational stage, and as knowledge and techniques are developed.

The projects which I have outlined cover a wide span of interests and specialties. The individual project leaders and staff of the Minnesota district would welcome the opportunity to discuss any of these projects with you further. The new approaches, criticisms, and ideas which evolve from these discussions would be most helpful.

ONGOING WATER RESOURCES RESEARCH IN MINNESOTA, AGRICULTURAL RESEARCH SERVICE, USDA 1/

BY

CORNELIUS A. VAN DOREN 2/

Introduction

Research of the Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Dept. of Agriculture, is cooperative with the state agricultural experiment stations. In the Corn Belt Branch of the Division, cooperative research is supported in the states of Minnesota, Iowa, Missouri, Illinois, Wisconsin, Indiana, and Ohio. In Minnesota, cooperative work is underway at the North Central Soil Conservation Research Center at Morriss, on the St. Paul Campus, (Institute of Agriculture), and at the St. Anthony Falls Hydraulic Laboratory, Univ. of Minn., Minneapolis. The program attempts to solve the problems of regional concern in the area of soil and water management, including some of the problems associated with environmental quality.

The purpose of this discussion is to present a brief description of some water resources research activities being conducted within the State of Minnesota. Mention will be made of ongoing research in other states, only in two cases where complementary research on water quality may be of interest.

Research Activities

Agricultural research is concerned with the land phase of the water cycle from the contact of rain and snow with vegetative canopy or ground surface and the use and disposition of the water before it returns 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; quality of water entering streams and aquifers; water use efficiency by economic plants; and predictive procedures on the operation of the complete hydrologic cycle." (15)

The efficient use of precipitation and soil moisture in crop production is one of the continuing studies at Morris. Evapotranspiration exceeds normal amounts of rainfall received throughout much of the growing season for corn. The imbalance is particularly severe during the critical tasseling and grain filling period. Therefore, corn yields in the western

1/ Contribution from the Corn Belt Branch, Soil & Water Conservation Research Div., Agricultural Research Service, USDA, St. Paul, Minn., in cooperation w/ Minn. Agric. Experiment Stn., St. Paul, Minnesota.

2/ Agricultural Administrator, U.S.D.A. and Professor of Soil Science, University of Minnesota, St. Paul.

Corn Belt are extremely dependent upon the amount of stored soil moisture at the beginning of the cropping season and upon precipitation distribution and amounts during the growing season (6, 7, and 8). Precipitation received during late July and early August has a greater effect on corn yields than that received in late June or early July. With 3 inches of rainfall during tasseling and grain filling, corn yielded in excess of 100 bushels per acre. With the same amount of soil moisture, but with only 0.5 inch of precipitation, corn yielded approximately 40 bushels per acre. Subsequent comprehensive water use efficiency studies have shown that evapotranspiration is quite constant for a given crop under field conditions, and the water use efficiency (expressed in bushels of corn or soybeans per inch of water used) increases as yield increases (5, 13, 14).

Current research in this area attempts to improve soil moisture retention and efficiency of water use through tillage and soil management systems. The effect of various tillage operations on infiltration and movement of water through soil is being studied. Rough plowing has increased moisture retention and infiltration (3).

The objective of present studies is to describe the mechanism by which tillage-induced conditions affect the net soil-water storage under conditions of restricted runoff, particularly during summer months. Studies are under way to determine the influence of crop residue mulches on crop response and water use efficiency. A method has been developed for determining rooting patterns of various crops. By studying rooting habits and relating this information to moisture extraction, we can better understand the plant's response to moisture stress and moisture excess in soil profiles.

Sediment is still considered the number one pollutant of streams and water supplies. The sediment originates from soil erosion on agricultural land, urban construction, highways, and other sources, The Corn Belt Branch has a team attempting to develop and test a generalized, mathematical model describing the process of soil erosion by water. The four general interacting components of this model are: soil detachment by rainfall, soil detachment by runoff, transportation by rainfall, and transportation by runoff. At Morris, a raindrop tower is used to determine how the energy of raindrops affects soil detachment and transportation. High-speed movies of splash characteristics evaluate the influences of surface conditions and depth of impounded water on soil erosion (10).

Other studies on permanent runoff-soil loss plots and on plots to which artificial rain is applied are measuring susceptibility of different soils to erosion. The efficiency of various cropping and conservation practices in reducing runoff and erosion is under investigation. Studies indicate that practices that can increase infiltration 1.25 inches on 6% slope Barnes loam during the 2-month period following corn planting will eliminate erosion hazard from land in continuous corn.

Closely related to the moisture-use efficiency and erosion studies at Morris are cooperative studies being conducted by five research soil scientists located on the St. Paul Campus, Institute of Agriculture. This group is attempting to develop theories and practices for describing and control-

ling the structure of soil. They visualize the pore system of a soil as a flow network for transport of water and air. They are searching for meaningful physical parameters that will describe the pore network. Hopefully, from these parameters, predictions can be made for air and water flow as well as nutrient transport through soil. Currently, an improved model for predicting the unsaturated water conductivity of soil from the suction-water content curve is being developed. In associated work, computer simulation techniques are used to view the soil as a two-dimensional network of interconnected pores having a pore size distribution defined by the moisture-characteristic curve. In this way, it is hoped that the importance of various parameters for describing the pore system can be evaluated. In other work, transport of nutrients and gasses by fluctuations in fluid velocity in soils is being studied.

The solid matrix of a soil is a plastic body through which plant roots grow. As roots penetrate through fine-structured soil, they must exert forces that deform the matrix. Currently, a study is under way to determine whether metal probes can be used to simulate the forces exerted by plant roots and if they can be used as a diagnostic tool for predicting root growth. If metal probes can be used to simulate roots, much time and effort could be saved in plant root behavior studies. Associated studies concern measurement of the mechanical properties of soil and development of theories for predicting their behavior under loading.

The forces holding soil particles together often become very weak as the soil nears saturation. The forces of raindrop impact can thus detach particles so that they are transported in runoff water. Often during rainfall, the soil just beneath the surface is under a slight suction. The magnitude of this suction determines to a large extent the strength of the soil and thus its ease of detachability.

Because the arrangement of the solid particles defines the pore network of soils, a better understanding is needed of the forces that bind particles together. We know that organic matter and clay are major bonding agents. Our group has a great deal of research information on the strength of different clay-organic bonds and which organic compounds are important in stabilizing the solid matrix into a porous system. Recently, a technique has been developed for measuring the tensile strength of oriented clay films as influenced by water content and saturating cation. The work is now being extended to measurement of clay films that have adsorbed organic compounds.

Brickbats are being thrown at agriculture for polluting lakes and streams with nitrogen, phosphorus, pesticides, etc. It is time to gather facts without becoming emotionally involved. Research in this important area is being accelerated by state agricultural experiment stations and ARS. Water quality studies were initiated at Morris in 1966. Congress has appropriated funds for an expansion wing to the Morris laboratory for an enlarged program to determine the extent of nutrient enrichment of surface waters and to devise practices to reduce agricultural contribution to pollution. Surface runoff from agricultural land cannot be eliminated. But practices can be devised to essentially eliminate soil erosion with the attendant sedimentation of streams, lakes, and water supplies. These practices, however,

may be too costly for individual farmers to undertake.

Contrary to many recent views from the popular news media, the major source of nitrogen and phosphorus for crops and forages produced in Minnesota is not commercial fertilizers. Crops obtain most of their nutrients from the nutrient supply occurring naturally in the soil. About one-fourth of the nitrogen and one-third of the phosphorus come from applied fertilizers. Even before increased use of fertilizer, following W.W. II, the fields of Minnesota were contributing nutrients to streams and lakes. Agriculture's contribution to eutrophication, which is progressing at a more rapid rate now than formerly, is not known. The bogs of northern Minnesota are proof that eutrophication and aging can occur in lakes without the help of runoff, sediment, and nutrients from farmland.

In an effort to understand the extent of nutrient enrichment of waters under natural conditions, two studies are under way: one involves determination of nutrients from a native grass area and the other, in cooperation with the Forest Service, involves measurement of nutrients in runoff into, and discharge from, a bog. By understanding what happens without man's intervention, we will be better able to determine what can be done on farmlands.

Early studies indicate large quantities of nitrogen and phosphorus in runoff and eroded soil and sediment (4). Most of the phosphorus is insoluble in water. In fact, sediment has a high capacity for removing phosphorus from water (13) Little is known about the effect of organic nitrogen in sediment on eutrophication. Under aerobic conditions in shallow lakes, this fraction may contribute both nitrogen and CO_2 for plant growth. However, under anaerobic conditions, denitrification converts nitrate into elemental nitrogen which returns to the atmosphere.

Snowmelt runoff may be a major contributor to nutrient enrichment of water in streams and lakes in Minnesota (12). Results at Morris in 1967 indicate that as much as 0.34 pound per acre of phosphorus was carried in snowmelt from hayland, while that from cornland contributed only 0.01 pound. Phosphorus in summer runoff from cornland was 0.06 pound per acre as contrasted with only 0.01 from hayland. Nitrogen losses followed the same pattern with greater losses from snowmelt runoff than from rainfall runoff. Current research suggests that plant cells that have been ruptured by freezing readily release nutrients to snowmelt runoff. These losses will be extremely difficult to control, but every effort must be made by agricultural research agencies to find economically feasible practices to reduce the hazard of nutrient enrichment of water resources.

Current studies at Morris are designed to determine the influence of vegetation on nutrients in runoff and to determine the effect of tillage and placement of fertilizers on nutrient losses in surface runoff. In a discussion of water quality studies, two experiments in progress at the Corn Belt Branch should be mentioned as the results may have significant applicability to Minnesota. In Ohio, two persistent pesticides, dieldrin and haptachlor, have been added to watersheds. The dissipation of these materials through runoff, soil loss, and volatilization is being measured.

Other divisions of ARS are developing biological control mechanisms for insects; i.e., sterilization by irradiation, use of wasps on pea aphids, and isolation of corn borer sex attractant.

Another study which should be mentioned is being conducted on watersheds in western Iowa. In this study, high rates of nitrogen and phosphorus are being applied to watersheds, terraced and unterraced, to determine the amounts of nutrients in surface runoff, base flow, and groundwater. For a 3-yr. period, terracing changed the pattern of water yields by increasing total base flow from 8.4 to 22.3 inches. During the same period, terracing reduced runoff from 15.1 to 3.7 inches (11). Hopefully, by increasing base flows, nutrients may be filtered out before water returns to surface flow.

A limited amount of work will be conducted at Morris in cooperation with the West Central Agricultural Experiment Station on controlling pollution from animal wastes. Major cooperative studies on this problem are under way in Nebraska and Colorado. Pollution of surface waters by runoff from feedlots in most cases can be controlled by maintaining closed systems where impounded runoff and wastes are spread over the land through an irrigation system. This type of recycling and reuse of our waste products is a challenge that must be met by all phases of production - agricultural, industrial, and municipal. A major unsolved problem is the large amounts of ammonia that are volatilized from feedlots (9). In the atmosphere, this ammonia is absorbed by free water surfaces and precipitation.

Another research group in Minnesota, located at the St. Anthony Falls Hydraulic Laboratory, is working on hydraulics of conservation structures. This group has designed or improved the designs of the SAF stilling basin, box inlet drop spillway and outlet, hood inlet for closed conduit spillways, and hydraulic characteristics of drain tile and fittings (1, 2). These findings have been widely applied by the Soil Conservation Service in the design of water conservation structures; by highway departments; airports; etc.

Current studies at the St. Anthony Falls Hydraulic Laboratory are emphasizing further testing and design improvements on hood drop inlets for closed conduit spillways. The hood inlet is widely used by the Soil Conservation Service in their P.L.-46 and P.L.-566 programs. Adding a drop inlet to the hood inlet will result in considerable savings in construction costs and will permit increased water storage without an increased height of dams.

A major study is under way on scour and protection against scour at structures to determine: the need for protective riprap, area requiring protection, and size of riprap required at the inlet and outlet structures. In 1968, 303 floodwater-retarding structures and 1665 grade stabilization structures were constructed under the direction of SCS. The Corps of Engineers also recognizes that many problems are associated with protection of structures. If eroded banks, wave wash, and scour can be eliminated, public concern regarding safety of dams can be prevented and recreational value of projects can be enhanced.

In conclusion, much of the work by the Soil and Water Conservation Research Division, Agricultural Research Service, is oriented toward gaining a better understanding of the soil-plant-water-atmosphere system. Agriculture through its past cooperative Federal-state research programs has developed an expertise in solving many soil and water resource problems. Many additional environmental problems relating to our water resources are of great public concern and demand immediate attention. If we accept the responsibility and the challenge, agriculture should be able to continue producing food in abundance without polluting surface and ground waters.

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WATER RESOURCES RESEARCH IN MINNESOTA BY THE NORTH CENTRAL FOREST EXPERIMENT STATION, USDA FOREST SERVICE

BY

ROGER R. BAY 1/

The North Central Forest Experiment Station is responsible for Federal forest research in the north-central part of the US, including the State of Minnesota. In the field of watershed management research, the Station has research projects in Michigan, Wisconsin, and northern Minnesota. This paper will deal primarily with research in the northern peatlands of Minnesota, but forest ground-water studies now underway in Michigan should also provide valuable information for the management of forest stands on similar areas in Minnesota. Moreover, current studies on runoff and erosion reduction processes in southwestern Wisconsin (the nonglaciated area) are yielding information directly applicable to southeastern Minnesota.

Minnesota contains approximately 7 million acres of organic soils, much of this located in the northern part of the State. These northern peatlands vary from nonproductive sites to land that produces high-quality pulpwood. They are also considered strategic watersheds which form the headwater basins for the Rainy, St. Lawrence, and Mississippi Rivers. Many streams arise in the high water-table organic soil bogs. Thus, the peatland area might also be considered a supplier of water

Experimental Watershed Studies

The influence of peatland management on runoff is being studied by the experimental watershed method. Six watersheds were selected for study in 1961-62. Each consists of an individual peat bog from 6 to 37 acres in size (representing from 12 to 33 percent of the total watershed) completely surrounded by upland, mineral soils. The bogs support nearly mature stands of black spruce while well stocked aspen stands grow on the surrounding mineral soils. Total watershed size, including the bog and mineral soil complex, ranges from 22 to about 130 acres.

Runoff from the watersheds is measured with weirs and flumes on small, natural streams draining the peatlands. Precipitation gages and recording and nonrecording wells are also located in the bogs. Deep wells have been drilled in the nearby upland areas to measure changes in ground-water storage and to relate individual bogs to the surrounding ground-water system. Water storage in the surrounding mineral soils is measured with a neutron soil moisture probe. Thus all incoming water, water storage changes within

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the bog and mineral soils, and all outgoing water are accounted for on each watershed.

Data have been collected on these bogs for the past 8 years. High correlations and accurate prediction equations have been obtained for comparing annual runoff, seasonal runoff, and various aspects of high and low flows among bogs during this calibration period. One watershed has now been selected as a control. On the other watersheds, various forest treatments have been planned to determine their possible influence on water levels and runoff. This control-watershed approach has been used in a number of forest and agricultural watershed experiments in the U.S. and Europe but has not been applied in peatlands similar to those in northern Minnesota.

One bog was treated in early 1969 to test the influence of clearcut strips on the runoff regime. Eight strips of trees, approximately 100 ft. wide and 400 ft. long, were clearcut at equal intervals across a 20-acre bog. Water levels in the bog and runoff after this treatment will be compared with values predicted from the control watershed. In another study, all of the trees on the upland portion of one of the experimental watersheds are now being harvested to determine the influence of upland forest cutting on the total runoff regime, including water quality. Other treatments, such as forest water level control or temporary impoundments, will be applied to some of the experimental bogs in the future.

We have also studied water quality in the bogs. Specific conductivity, temperature, pH, and such nutrients as iron, calcium, sodium, potassium and nitrogen were measured. These measurements will be continued after treatments are made to determine the effect of bog management on the quality of runoff water.

Although the main purpose of these experiments is to discover how water yield and quality can be changed by forest land management, we have also learned about the natural runoff pattern from bogs during this calibration period. Many people have considered peatlands to be important regulators of streamflow, retaining water during wet periods and slowly releasing water to sustain streamflow during dry seasons. However, our experimental bogs have not functioned in this way. In these study bogs most of the runoff occurred during the spring months of April and May, and during the summer months, runoff was low, even though summer rainfall was high (fig. 1).

High runoff in the spring is a result of high water tables, snowmelt, and spring rainfall. Because of low evapotranspiration, water tables remain near the bog surface. Little storage space is available in the bogs and much of the snowmelt water and spring rainfall runs off. Average spring runoff for the last 6 yrs. has been approximately two-thirds of the annual water yield from the experimental bogs (table 1). In some years, spring water yield was over 80% of annual runoff.

The hydrologic characteristics of these peatlands have been largely ignored until recent years. Today, however, people are beginning to look upon bogs and swamps as important landscapes within our natural environment. They are becoming concerned with the hydrology of natural peatlands and how

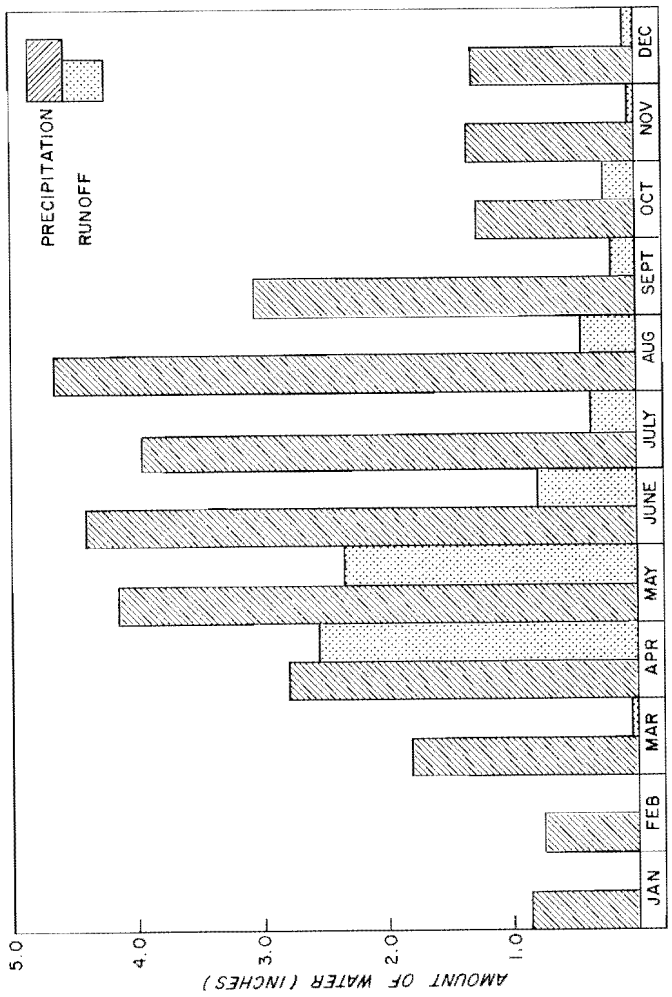

Figure 1. Average monthly precipitation and runoff for and 86 acre watershed containing 20 acres of bog. (From Bay, Roger R. 1969 Runoff from small peatland watersheds. J. Hydrology 9: 90-102.)

hydrologic relationships might be changed with various land management activities such as timber harvesting or water-level control. Because of this concern, the USDA Forest Service began research in peatland hydrology about 9 yrs. ago in Northern Minnesota. The Bog and Swamp Hydrology Project, currently staffed with 4 professional scientists and several technicians, is headquartered in Grand Rapids. The objectives of the research program are to develop forest and land management practices that will maintain and improve water yield, increase low flows in late summer, and protect water quality on peatland watersheds. Current research is under way on experimental watersheds, field plots, and in the laboratory.

During the summer months most of the monthly rainfall is lost through evapotranspiration and little water is available for runoff. During dry periods, perennial storage has not been sufficient to sustain streamflow, and runoff often stopped. Thus, the bogs did not store water for long periods and they did not regulate streamflow over long time periods.

However, peak rates of runoff are low, indicating some short-term water storage in the bogs. Annual peak flow rates occur in the spring and have ranged from a few cubic feet per second per sq. mile to about 35 c.s.m. Summer peaks are normally lower because high evapotranspiration from the bog vegetation lowers water tables, making more storage space available for summer rains. Low peak rates of flow have been directly associated with low water tables. Also, the nearly flat topography of the bogs causes some delay in runoff.

Runoff relationships are not the same on all peatlands. The runoff patterns descri ed above were measured on perched bogs that received no recharge from ground water. Some peatlands receive water from regional underground basins and their runoff characteristics are probably different. These are called ground-water bogs. Relationships between bog-water tables and the regional ground-water system are also being studied.

Ground-Water Studies

Deep wells have been drilled in the uplands surrounding each bog to study the surrounding ground-water system. These wells indicated that all but one of our study bogs are perched above and isolated from the underground basin. Precipitation is their primary source of recharge and it appears that they in turn add little, if any, water to the underground system. However, one of our study bogs is receiving recharge from the surrounding ground-water basin and its vegetation and hydrology differ from the perched bogs. The peat is less acid and more nutrients are present in its waters. Moreover, the greater variety of plants and better forest growth are associated with this bog. The vegetation tends to be more eutrophic in this ground-water bog while in the perched bogs the plant communities tend to be oligotrophic, or nutrient-poor.

Water-table fluctuations and runoff from the perched bogs depend mostly upon precipitation characteristics. But in the ground-water bog, changes in the surrounding ground-water system also affect the bog-water table. Continuous ground-water discharge to the bog causes higher and more stable bog-water

Table 1.--Percentage of water yield occurring by seasons -- 6-year average, 1962-67

Season[1/]	Watershed			
	S-1	S-2	S-4	S-5
Spring	63	60	71	70
Summer	26	26	21	22
Fall	11	13	7	8

[1/] Spring, March 1 to June 1; summer, June 1 to September 1; fall, September 1 to December 1.

Table 2. Hydrologic characteristics of several peat materials[1/]

Material	Bulk density	Water yield[2/]	Rate of water movement
	g./cc.	gal./cu. ft.	ft./day
Undecomposed moss	0.04	4.5	108.00
Partly decomposed herbaceous peat	.156	.9	.02
Well decomposed peat	.261	.6	.01

[1/] From: Boelter, D. H. 1969. Important physical properties of peat materials. Third Int. Peat Congr. Proc., Quebec, 1968: 150-154.

[2/] Water yield determined between saturation and 0.1 bar suction.

tables and less variation in runoff. Further study of the relationship between bogs and the surrounding ground-water systems is now being done with geophysical techniques. Seismic refraction, electrical resistivity, and gravity methods are being used to determine the size of the underground basin recharging our ground-water bog. An electric analog model of this bog and the surrounding ground-water system is now being constructed from these data. It has become evident that knowledge of ground-water conditions is necessary to fully understand the hydrology of peatlands.

Organic Soils Studies

Research on the physical properties of undisturbed peat materials has been done in an effort to better understand the organic soils involved and interpret bog-water table fluctuations and runoff. Just as in upland watersheds, the soils of a bog form the reservoir where water is stored. Storage capacity and water movement rates in the soil influence water-table fluctuations and also the release of water to streamflow.

Soil physics studies have shown that water storage properties of organic soils vary greatly with different types of peat. In the field, piezometers have been used to measure the rate of water movement in vertical and horizontal zones within different peats. Both water-storage properties and hydraulic conductivities vary with bulk density and decomposition. The more decomposed, denser peats have smaller pores and yield only small amounts of water. Undecomposed moss peats, however, have large pores that can be easily drained. (table 2).

High rates of runoff from peat bogs are associated with high water tables because less decomposed peats are usually found near the bog surface and the large pores of these peat types allow rapid water movement to the bog outlet. During the growing season, when evapotranspiration lowers water tables, less water is available to runoff because the deeper peat materials are usually more decomposed and retain more water. Thus, the hydrologic reaction of individual peat bogs can often be related, in part, to the physical and hydrologic properties of the organic soils within the zone of active water-table fluctuation.

Recently, additional studies have been started to determine the influence of water control practices on the physical properties and water storage characteristics of organic soils. Wells and piezometers are being used to measure the patterns of water flow into and around drainage ditches when water tables are at different depths. Future studies will determine the influence of different drainage intensities on water storage characteristics, evapotranspiration loss, and on the amount and timing of runoff from various organic soils.

Future Research

Besides the new studies already discussed, future research will be concerned with studying methods of managing peatlands to increase low flows in summer. Studies designed for this purpose will be concerned with reducing evapotranspiration and increasing runoff through vegetation management and water-table control. The distribution of energy in peatlands, evaporation suppressants, the control of soil water by ditching systems,

and perhaps seasonal flooding techniques, will all be considered. Techniques of instrumentation and measurement will need to be refined in the field and laboratory. The most promising systems will be tested on experimental areas in the field.

The possible influence of these wildland management practices on water quality will also be measured. Several years of quality data from undisturbed bogs have provided important background information prior to treatment. As new studies are initiated, attention to water quality will be emphasized. Minnesota's northern forest land will be receiving more and more use in the future--from the forest production standpoint as well as for other uses. We hope that the present research program will help show how to manage these areas so as to protect and enhance the valuable water resource flowing from them.

Evapotranspiration Studies

Evapotranspiration losses from peatlands have been studied by two methods. One method used bottomless evapotranspirometers to measure the amount of evaporation from a treeless bog. Water loss measured by this technique compared favorably with pan evaporation and potential evapotranspiration as computed by the Thornthwaite method. In a second study total watershed evapotranspiration was calculated using precipitation, runoff, and water storage data from individual peat bogs. These water balance computations indicated a close correlation between actual water loss and potential evapotranspiration for a 6-month season. Computations for short-term drying seasons, however, suggested that evapotranspiration did not reach potential when water tables were only 30 cm. below the average moss surface.

Recently, studies have been begun to evaluate the energy regime in different types of peatland vegetation. A cooperative study with the University of Minnesota School of Forestry has measured the albedo (reflected incident solar radiation) of a black spruce stand, open sphagnum bog, and various other cover types. The data are now being analyzed to determine possible differences in energy available for the evaporation process.

Additional studies have been initiated to measure various components of the energy regime in a natural black spruce forest, the influence of water levels on several aspects of bog microclimate in the field and in a growth chamber, and the effect of forest cutting on energy storage in a peat bog. Such studies should help explain the effects of different forest and water-level-control treatments on evaporation and runoff from the experimental bog watersheds and help interpret potential treatment effects on other areas.