WRRC
Bulletin 111

EIGHTEENTH ANNUAL REPORT
WATER RESOURCES RESEARCH CENTER

Prepared by:
George R. Blake, Director
Elizabeth Espointour, Secretary

WATER RESOURCES RESEARCH CENTER
UNIVERSITY OF MINNESOTA
GRADUATE SCHOOL

A Report of Activities Supported by the Graduate School and the U.S. Department of the Interior During the Fiscal Year Ending September 30, 1982.

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October, 1982

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PREFACE

The Eighteenth Annual Report of the University of Minnesota Water Resources Research Center presents a summary of activities for fiscal year 1982. It covers the period October 1, 1981 through September 30, 1982.

The Report describes the research activities of the Center, its involvement in training water scientists and its efforts in transferring technologic information to potential users.

Research progress reports of seven sponsored projects are included in the report. A summary of students employed and given water sciences training through the Water Resources Center are presented.

The work upon which this publication is based was supported in part by funds provided by the United States Department of the Interior as authorized under the Water Research and Development Act of 1978, P.L. 95-467.

DIRECTOR'S REPORT 1982

The Water Resources Research Center at the University of Minnesota continued an active research and information dissemination program in 1982 despite severe funding uncertainties. As of this date we are beginning a second year of a Congressional continuation of funding at 1981 levels for the annual cooperative program. The matching grant program did not exist in 1982. Thus there was an attrition in our research program. This was exacerbated by the expiration of special grants from agencies that also felt the squeeze on available funds. Thus, overall, our budget fell below that of 1980 or 1981, a drop of 29 percent from FY 1981 to 1982.

The result of budget cuts means essentially a reduced number of research projects. But publications and information dissemination programs were also reduced.

Research Program

Seven projects were supported from the Water Resources Research Center in 1982. These addressed questions of recharge of surficial aquifers and groundwater, the effects on wetlands ecosystems of runoff from agricultural lands, the loading of soils by septage disposal, zeolites for removal of heavy metals from water, the economic efficiency of irrigation in Minnesota's corn belt and the mathematical hydrologic simulation of critical watersheds.

Some of the findings of these researches are as follows:

Agricultural Engineers Donald C. Slack and Curtis L. Larson (A-043) with student assistants Brian Enock and Mark Klassen have developed evapotranspiration and snowmelt submodels to be fitted to field measurements of surficial aquifer water levels and weather data to predict recharge of the aquifers.

Biologist Gerald L. Van Amburg (A-044) with student assistants Richard Williams, Dennis Leland, Karen Almquist and Carlene Paulson, has collected and is analyzing samples of watershed runoff, wetland water and wetland sediments to piece together a picture of the affects of agricultural runoff on natural wetland ecosystems.

Agricultural Engineers Charles J. Clanton and Roger E. Machmaier and Soil Scientist James Anderson (A-045) assisted by Dana Danes and Martha Kennedy showed that soil texture plays a vital role in determining the nitrogen content of the water in soil to which septage has been added. In sandy soils, nitrates are mobile and move through the profile rather rapidly. On clay soil nitrogen is lost by dentrification or it accumulates to be solublized by nitrification over a longer period of time following septage application.

Environmental Engineer Michael J. Semmens (A-046) assisted by Yuan Ming Tang has designed and constructed a bouyant media filter for purifying water that gives a very low headloss at design loadings of 2 to 5 gpm/ft^2 which are typical of practice. The filter is now being tested.

Horticulturists Ok Young Lee-Stadelmann together with her husband Eduard J. Stadelmann (A-047) and student assistant Denise Knuth are inducing drouth hardiness in <u>pisum sativum</u> plants under controlled environments with the goal of increasing water use efficiency. They have found that osmotic adjustment is taking place under the stress treatment applied.

Agricultural economist Vernon R. Eidman and Agronomist Craig Schaeffer (B-158) assisted by Paul R. Carter, David J. Nielsen and Darrell Bosch are using crop models to evaluate irrigation strategies for soybeans with a view toward increasing economic efficiency of water use for irrigation.

Civil Engineer C. Edward Bowers (B-161) together with student assistants C. Teng and Joel Toso are fitting two hydrologic mathematical simulation models to selected watersheds to monitor the quantity and quality of streamflow.

Technology Transfer

Technical papers resulted from researches funded by WRRC in 1982. In addition the Center published an annual report and a special report. Bulletin 108 is the 17th Annual Report of the Center. Continuing the research of Professor Henry W. Quade of Mankato State University, special report No. 3 by C. E. Larson-Albers of Mankato State University was published under the title The Impacts of Wetlands and Drainage on Water Quality in an Agricultural Watershed in South Central, Minnesota.

A council of Water Center Directors of the University of Minnesota was formed to coordinate research and teaching efforts. They have met twice on their first project which is to publish a brochure explaining to legislators, the public and University colleagues the purpose and role of each of the Centers. These Centers consist of the following:

Agricultural Experiment Station
Dr. Richard J. Sauer, Director
220 Coffey Hall
1420 Eckles Avenue
University of Minnesota
St. Paul, Minnesota 55108

Gray Freshwater Biological Inst.
Dr. Richard S. Hanson, Director
County Roads 15 & 19
Box 100
Navarre, Minnesota 55392

Lake Superior Basin Studies Center
Dr. Thomas J. Wood, Director
214 Research Laboratory Building
University of Minnesota
Duluth, Minnesota 55812

Minnesota Geological Survey
Dr. Matt S. Walton, Director
1633 Eustis Street
University of Minnesota
St. Paul, Minnesota 55108

Minnesota Sea Grant Institute
Dr. Donald C. McNaught, Director
116 Classroom Office Building
1994 Buford St.
University of Minnesota
St. Paul, Minnesota 55108

St. Anthony Falls Hydraulic Laboratory
Dr. Roger A. E. Arndt, Director
2 Third Avenue S. E.
University of Minnesota
Minneapolis, Minnesota 55414

Water Resources Research Center
George R. Blake, Director
866 Biological Sciences Center
1445 Gortner Avenue
University of Minnesota
St. Paul, Minnesota 55108

Limnological Research Center
Dr. Herbert E. Wright, Jr., Director
220 Pillsbury Hall
310 Pillsbury Drive S.E.
University of Minnesota
Minneapolis, Minnesota 55455

Education and Training

WRRC projects enabled 7 undergraduate and 8 graduate students to obtain part-time employment while pursuing their studies at the University. It supported the research activities of 12 professors in Minnesota Universities.

The role of the Water Resources Research Center is a central one in the University. Its mission of research is not orientated toward a single aspect of water. The program provides research grants to any person in any College or University in the state. If funds were provided, it could conceivably sponsor research similtaneously in all areas of Water Resources.

The Center is free to publish and disseminate any research information useful to citizens or agencies in the State. And indeed it does disseminate information in progress reports as it becomes available. Again, however, fund restrictions cut into our ability to do as much as we wish to do or as much as we believe would be useful to our clientele.

The Center encourages undergraduate students to become familiar with water resources in various departments through student employment. It encourages specialization through research assistants working on WRRC grants while obtaining M.S. and Ph.D. degrees. The Center has a large commitment to and an interest in higher education.

Budget

The Center's budget was $334,005 derived from the University of Minnesota, Concordia College, U.S. Department of Interior and U.S. Department of Agriculture.

Future Funding of the Center

As of October 1982 WRRC like most federally-funded programs is operating on a "continuation" resolution until December 16, 1982. At that time Congress expects to pass a budget.

Though the Water Resources Centers are confident that Congressional intent is to continue the water research program, the provisions of that funding are far from settled. The Senate has passed S2494, the Abdnor bill, the House has not yet passed a related bill, HR 6087, the Au Coin bill. Each of these bills has provisions that differ from the other.

Rather than outline the provisions of these bills -- neither of which may define those of the bill that will ultimately emerge -- suffice it to say that changes are expected that will require additional state matching beyond the 1 to 1 valid in previous years.

Congress seems to be convinced that it has a responsibility for continuing water research through the State Institutes. Actions by the Congress in December will be crucial to that responsibility.

Whatever happens in December and beyond, the Department of Interior has indicated that administration of the Annual Cooperative Allotment will be through the new Office of Water Policy. They abolished the Office of Water Research & Technology (OWRT) and it no longer exists. The matching grant program, temporarily on hold because it was not included in the 1982 or 1983 continuation resolutions, will be administered by the Bureau of Reclamation, U.S. Department of Interior.

Minnesota
Water Resources Research Center
University of Minnesota

ADMINISTRATION

President of the University . . . . C. Peter Magrath
Dean of the Graduate School . . . . Warren E. Ibele
Director, Water Resources Research Center . . . . George R. Blake
Secretary . . . . Elizabeth Espointour

Advisory Committee

University of Minnesota

C. Edward Bowers	St. Anthony Falls Hydraulic Laboratory
Kenneth N. Brooks	College of Forestry
Dwight A. Brown	Department of Geography
K. William Easter	Department of Agricultural & Applied Economics
Lowell D. Hanson	Department of Soil Science
Warren E. Ibele	Graduate School
Curtis L. Larson	Department of Agricultural Engineering
Walter J. Maier	Department of Civil & Mineral Engineering
Gordon D. Rose	Institute of Agriculture
Richard J. Sauer	Agricultural Experiment Station
Thomas E. Straw	Division of Science & Mathematics (Morris)
Matt S. Walton	Minnesota Geological Survey
Thomas F. Waters	Department of Entomology, Fisheries & Wildlife
Thomas J. Wood	Lake Superior Basin Studies Center (Duluth)
Herbert E. Wright	Limnological Research Center

State and Private Colleges

Norman J. Baron	Dept. of Geography, Winona State University
Steven A. Spigarelli	Center for Env. Studies, Bemidji State University
A. Joseph Hopwood	Dept. of Biology, St. Cloud State University
James T. Jack	Dept. of Geography, Mankato State University
Robert T. Moline	Dept. of Geography, Gustavus Adolphus College

State, Local, and Federal Agencies

Rollin M. Dennistoun	Minn. Department of Agriculture
Gene H. Hollenstein	Minn. Department of Natural Resources
Edwin H. Ross	Minn. Department of Health
Joseph E. Sizer	Minn. State Planning Agency
Jack C. Ditmore	Minn. Water Planning Board
Erling M. Weiberg	Minn. Water Resources Board

Marcel Jouseau	Metropolitan Council
Donald R. Albin	U.S. Geological Survey
Harry M. Major	U.S. Soil Conservation Service
Joseph Scott	U.S. Bureau of Sport Fisheries & Wildlife
Elon S. Verry	U.S. Forest Service

Interest Groups and Private Concerns

Douglas W. Barr	Consulting Hydraulic Engineer
Jeanne Crampton	League of Women Voters
Raymond A. Haik	Attorney
Ken Kadlec	MPIRG
Paul [illegible]	Izaak Walton League of America

Research Faculty

The following faculty members were principal investigators on Water Resources Research Center Projects in FY 1981.

James L. Anderson	Assistant Professor, Soil Science
C. Edward Bowers	Professor, Civil & Mineral Engineering
Charles J. Clanton	Instructor, Agricultural Engineering
Vernon R. Eidman	Professor, Agricultural & Applied Economics
Curtis L. Larson	Professor, Agricultural Engineering
Roger E. Machmeier	Professor, Agricultural Engineering
Michael Semmens	Associate Professor, Civil & Mineral Engineering
Craig C. Shaeffer	Assistant Professor, Agronomy
Donald C. Slack	Assistant Professor, Agricultural Engineering
Eduard Stadelman	Professor, Horticulture Science & Landscape Arch
OK-Young Stadelman	Research Associate, Horticulture Science & Landscape Ar
Gerald L. Van Amburg	Associate Professor, Biology, Concordia College

FISCAL YEAR 1982 OWRT BUDGET

Annual Cooperative Program

Project Title, Principal Investigator and OWRT Project Number	Federal Funds $
Center Directors's Office	53,259
Predicting Direct Recharge of Surficial Aquifers, D. C. Slack and C. L. Larson, Dept. of Agricultural Engineering, (A-043-Minn).	10,000
The Affects of Agricultural Runoff Upon Natural Wetland Ecosystems, G. L. Van Amburg, Biology Dept., Concordia College, (A-044-Minn).	11,700
Minimum Hydraulic and Nutrient Loading Rates of Septage to Soils, C. J. Clanton, Agricultural Engineering, (A-045-Minn).	11,600
Low Energy Filtration Using Bouyant Media Filtration, M. Semmens, Dept. of Civil and Mineral Engineering, (A-046-Minn).	12,829
Developing Water Use Efficiency for Crops (drought hardening for water conservation) E. J. Stadelmann and Ok Y. Lee-Stadelmann, Dept. of Horticultural Science and Landscape Arch., (A-047-Minn).	11,000
TOTAL	110,388
Annual Allotment Non-Federal Contribution	105,256

Matching Grant Program

Project Title, Principal Investigator and OWRT Project Number	Federal Funds $	Non-Fed. Funds $	Total Funds $
Increasing Economic Efficiency of Water Use for Irrigation in the Upper Midwest, V. R. Eidman, Dept. of Agricultural & Applied Economics and C. C. Sheaffer, Dept. of Agronomy & Plant Genetics, (B-158-Minn)	32,780	32,885	65,665
Mathematical Hydrologic Simulation of Critical Watersheds in Northeastern Minnesota, C. E. Bowers, Dept. of Civil & Mineral Engineering, (B-161-Minn)	17,152	17,152	34,304
TOTAL	49,932	50,037	99,969

WATER RESOURCES RESEARCH CENTER
UNIVERSITY OF MINNESOTA
SOURCES OF FUNDS

Fiscal Year	Center's Budget $	Federal (OWRT) $	Matching Monies				Special Grants
			U of M $	State College $	Private College $	Grad. School U of M $	
1965	84,564	52,297	7,474	0	0	24,793	
1966	195,362	106,980	78,336	0	0	10,046	
1967	214,767	113,333	92,567	0	0	8,867	
1968	220,525	135,396	78,054	0	6,575	500	
1969	262,819	166,508	91,944	0	3,867	500	
1970	328,160	180,930	123,035	20,795	0	3,200	
1971	338,872	192,846	109,022	29,495	4,011	3,500	
1972	432,777	240,856	156,126	27,622	1,473	3,700	
1973	373,672	199,236	151,855	14,815	4,268	3,500	
1974	441,680	255,179	180,969	0	2,032	3,500	
1975	378,584	229,636	145,448	0	0	3,500	
1976	271,079	163,159	107,920	0	0	3,500	
1977	340,910	177,411	165,468	0	0	3,500	
1978	307,949	152,962	134,986	5,724	0	3,500	
1979	320,922	176,375	144,547	2,232	0	3,500	
1980	395,736	174,985	169,351	3,000	0	3,500	44,000
1981	[illegible]	194,776	177,842	0	[illegible]	[illegible]	[illegible]
1982	334,005	160,320	150,342	0	14,654	0	8,689

WATER RESOURCES RESEARCH CENTER

Distribution of Federal Research Monies[1/]

1974-1982 inclusive

University Unit	Amount $
College of Agriculture	342,865
Agricultural Engineering	162,513
Agriculture & Applied Economics	43,665
Entomology Fisheries & Wildlife	23,395
Horticultural Science	11,000
Soil Science	102,292
College of Biological Sciences	14,406
Ecology & Behavioral Biology	14,406
Limnology (see IT)	
College of Forestry	77,981
Forest Resources	77,981
College of Liberal Arts	103,132
Anthropology	43,532
Sociology	59,600
Health Sciences	81,083
Public Health	81,083
Institute of Technology	368,657
Civil & Mineral Engineering	126,861
Geology & Geophysics	65,692
Limnology Center	118,933
St. Anthony Falls Hydraulic Lab	57,171
Minnesota Geological Survey	32,439
Concordia College	23,400
Gustavus Adolphus College	3,816
Mankato State University	30,000
University of Minnesota, Duluth	41,362
	1,119,141

1/ Excludes Administrative costs of the Water Resources Research Center

ANNUAL COOPERATIVE PROGRAM

NARRATIVE PROGRESS REPORTS

Annual Report -- Title I Projects

OWRT Project No.: A-043-Minn   Project Title: Predicting Direct Recharge of Surficial Aquifers

Agreement No.: 14-34-0001-2125

FCCSET Research Category: 02-A, 02-F, 02-G; 1, 5, 11

Name and Location of University Where Project is Being Carried Out: University of Minnesota, St. Paul, Minnesota

Project Began: October 1, 1979   Scheduled Completion: September 30, 1982

Principal Investigators	Degree	Discipline
Donald C. Slack	Ph.D.	Agricultural Engineering
Curtis L. Larson	Ph.D.	Agricultural Engineering

Student Assistants	Degree	Discipline or Academic Background
Brian Knoch	B.S.	Agricultural Engineering
Mark Klassen	Undergrad	Agricultural Engineering

A. Research Project Accomplishments

Water levels, soil moisture and weather data were monitored throughout FY 1981 at the site established on the Anoka sand plain. Figures 1-3 illustrate selected data over nearly three growing seasons and two winters. From this data it can be seen that the water table responds very rapidly to precipitation during frost-free periods. The data also shows that the water table rises very rapidly after the spring thaw in late March or early April. During the frozen soil period, it is interesting to note that the water table declines at a nearly constant rate which is nearly the same for both the 1980-81 and 1981-82 winters. This is most likely due to lateral movement but may also be in part due to moisture movement to the frozen soil zone in response to thermal gradients.

The evapotranspiration (ET) submodel has been developed and tested. The ET submodel allows for extraction of water from the soil based on the type of crop, time of year, and moisture status of the soil. To allow crop flexibility, the basic input includes: the rooting depth, the number of soil zones in the rooting depth, the fraction of the ET to extract from each zone as a function of time of year, and the crop coefficient as a function of time of year. Potential evapotranspiration is calculated on a daily basis using either the pan equation (based on pan evaporation) or Hargreaves' equation (based on average daily temperature, average daily relative humidity, and day length). The two methods were found to be about equal in ability to predict daily potential evapotranspiration. It is then determined if the rooting zone is water limited. If not, the ET is taken as equal to the potential ET. If so, the soil water to be extracted as ET is calculated as a fraction of potential ET depending on percent of available water remaining in the soil.

The redistribution submodel also has been developed and tested. It allows for one-dimensional movement of soil water (upward and downward) based on Darcy's law. Within a time step Darcy's law (unsaturated flow) is applied between adjacent soil zones beginning with the zones near the ground surface and proceeding down to the soil zone above the water table. The zone above the water table is maintained at field capacity. If after redistribution there is a surplus of water in this zone, this water is used to raise the water table. A deficit (below field capacity) causes a drop in the water table in order to bring the zone to field capacity.

The snowmelt process and infiltration into frozen soils proved to be complex heat and mass transfer problems. To take a theoretically based approach required many parameters most of which were unavailable or very difficult to measure. Thus, this approach was abandoned for a simpler one. The snowmelt model allows as input the date of frost in and the date of frost out of the ground. Before frost in and after frost out the growing season model consisting of the evapotranspiration, redistribution, and infiltration submodels is operated. Between frost in and frost out the ground is assumed to be impermeable except for the top soil zone which is allowed to become saturated with melt water. Snowmelt is calculated from an equation based on degree-days, base temperature = 32F, and solar radiation. The snowmelt is then allowed to be stored in the top soil zone, in surface depressions, and in the snowpack. Any excess is assumed to runoff.

B. Publications

None.

C. Project Status

This is the final year of the project. However, the project completion date has been extended to March 31, 1983. This will allow completion of all project objectives.

D. Application of Research Results

The U.S. Geological survey and Minnesota Geological survey have cooperated on the data collection phase of the project and will utilize the soil moisture and groundwater data in their programs. In addition, the USGS has expressed considerable interest in the evapotranspiration portion of the model and may utilize it in some watershed studies.

The Minnesota Department of Natural Resources, Division of Waters, have expressed interest in using the model to assess groundwater recharge in irrigated areas utilizing water from surficial aquifers. The model should be equally useful to other states with similar aquifers.

E. Work Remaining and Progress Contemplated During FY 1983

The submodels (evapotranspiration, redistribution, infiltration, and snowmelt) will be combined to produce a complete groundwater recharge model. The model will be verified using soil properties and meteorological data from the Andover sand plain test site. After this, the model will be applied to the Bonanza Valley to predict the effect of different crop and surface treatments on groundwater recharge.

Groundwater, meteorological and soil moisture data collection will continue at the Anoka site for the foreseeable future.

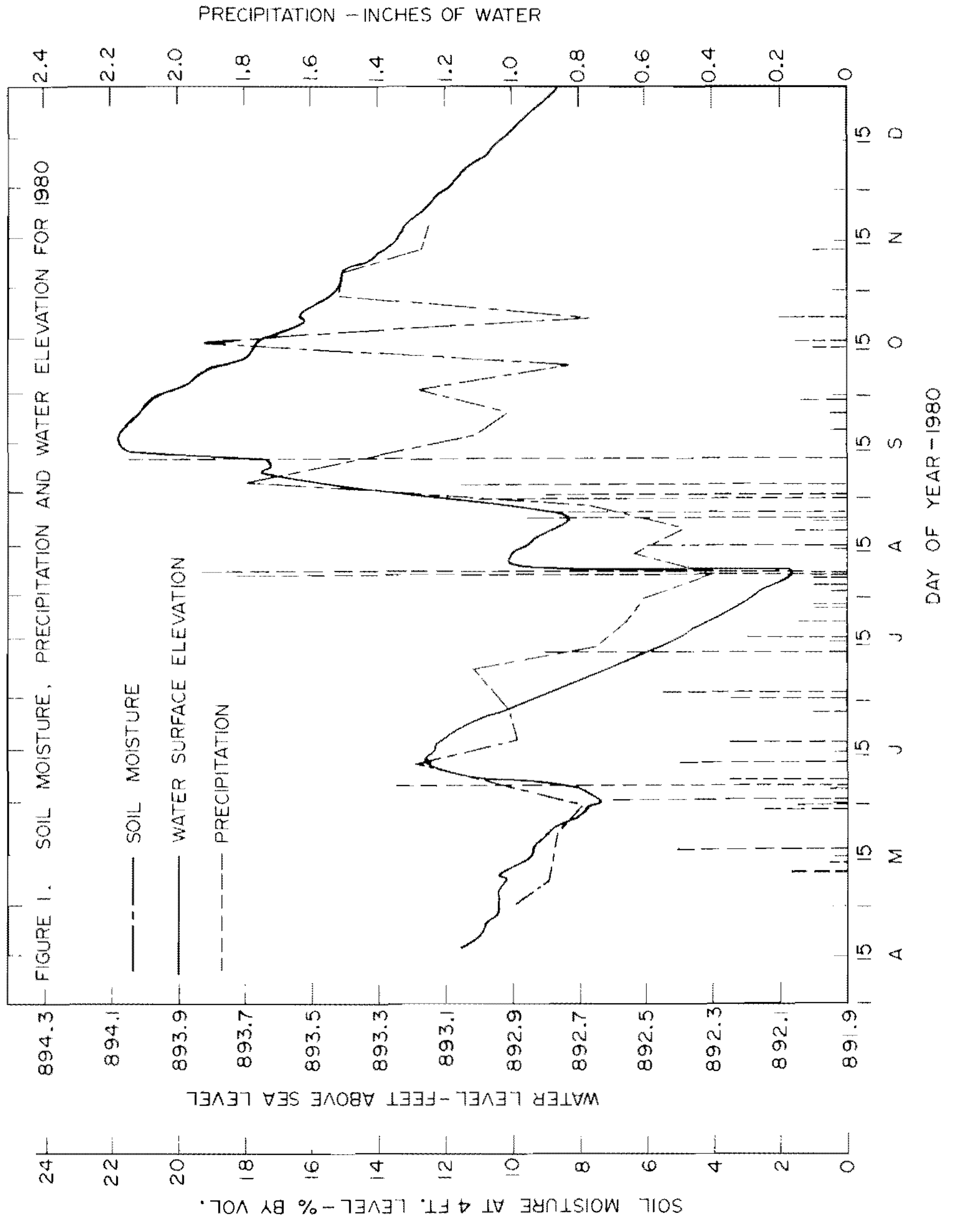

FIGURE 1. SOIL MOISTURE, PRECIPITATION AND WATER ELEVATION FOR 1980

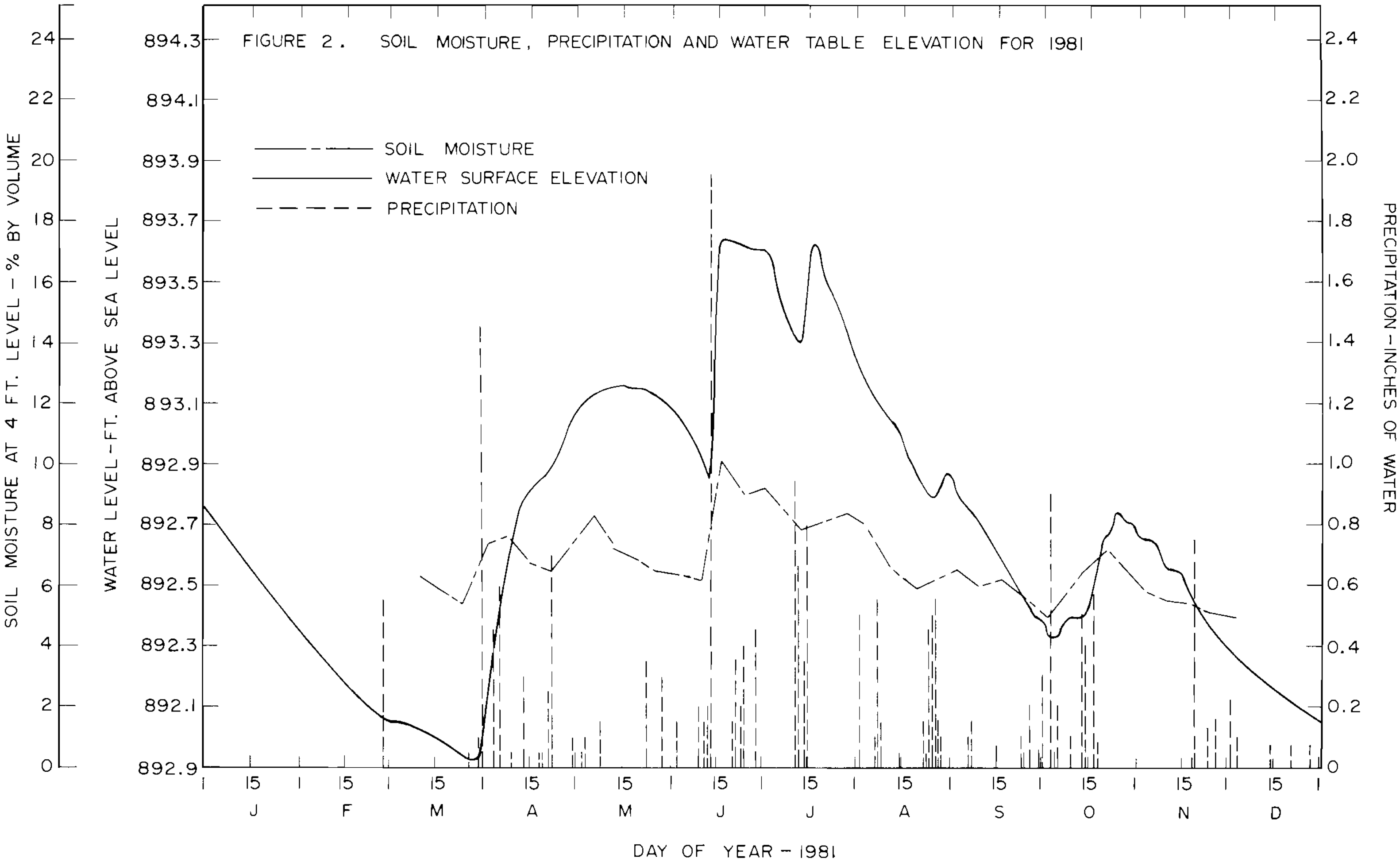

FIGURE 2. SOIL MOISTURE, PRECIPITATION AND WATER TABLE ELEVATION FOR 1981

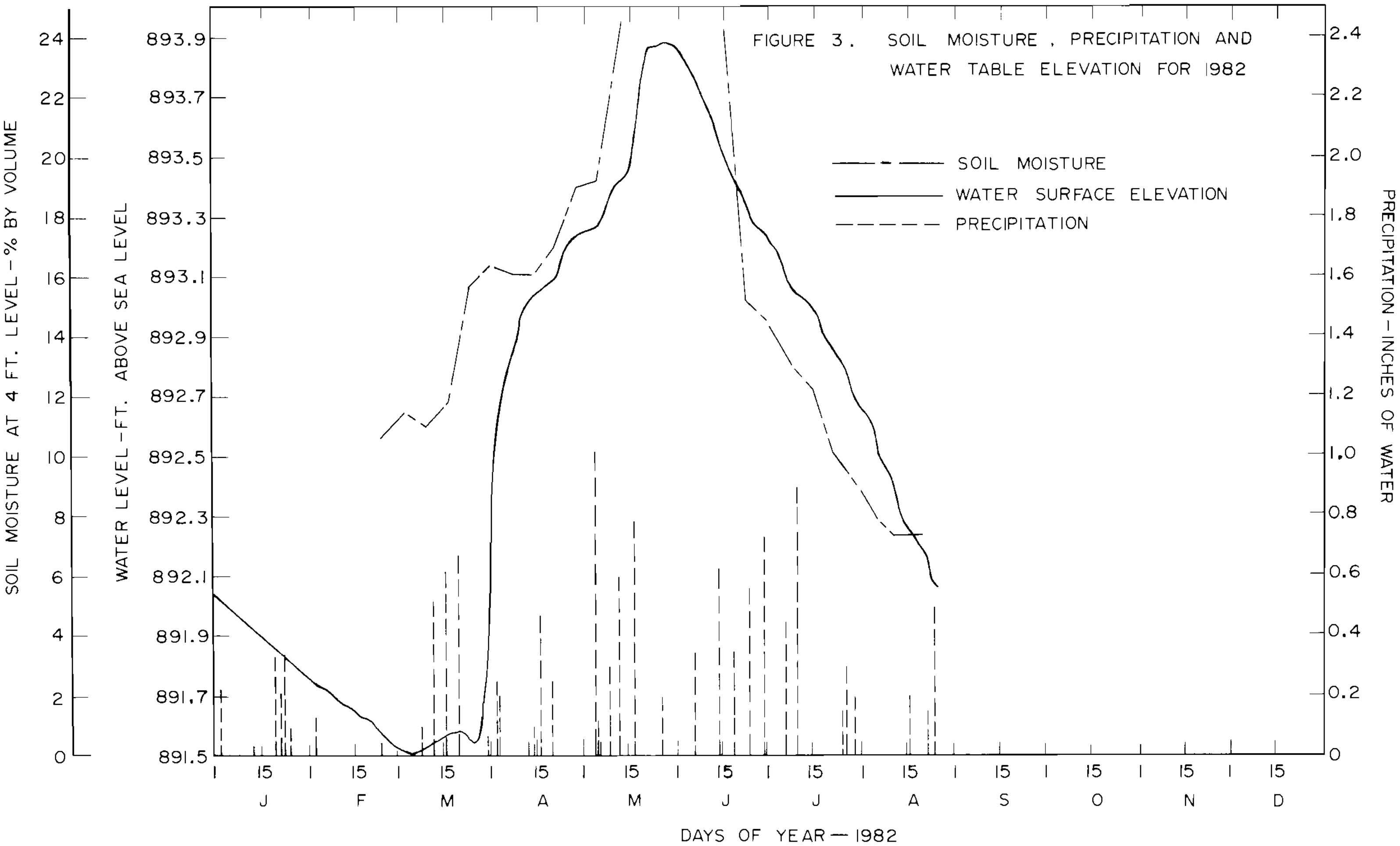

FIGURE 3. SOIL MOISTURE, PRECIPITATION AND WATER TABLE ELEVATION FOR 1982

OWRT Project No.: A-044-Minn

Project Title: The Affects of Agricultural Runoff Upon Natural Wetland Ecosystems

Agreement No.: 14-34-0001-2125

FCCSET Research Category: IV, A

Name and Location of University Where Project is Being Carried Out: Concordia College, Moorhead, Minnesota

Project Began: October 1, 1980 Scheduled Completion: September 30, 1982

Principal Investigator	Degree	Discipline
Gerald L. Van Amburg	Ph.D.	Range Science (Ecology)

Student Assistants	Degree	Discipline or Academic Background
Richard Williams	B.S.	Biology
Dennis Leland	Undergrad	Biology
Karen Almquist	Undergrad	Biology
Carlene Paulson	Undergrad	Biology

A. Research Project Accomplishments:

Two wetlands were selected as study sites for the project during Fall 1980. One site is located in Ottertail County, Minnesota (Sec. 1 & 2, T132N, R44W) and the other in Clay County, Minnesota (NE 1/4 SE 1/4, Sec. 29, T138N, R44W). The watersheds for both wetlands are cultivated, the principal crops being small grains, corn, soybeans, or sunflowers. The owners were interviewed and a recent history of crops, fertilization and pesticide application was recorded.

Collection of the second years data began May 14, 1982. Three of the compartments analyzed during 1982 were the same as those in 1981. These were: (1) watershed runoff, (2) wetland water, and (3) wetland sediments. Watershed soils and emergent vegetation were system compartments sampled during 1982. The wetland submergent vegetation compartment was added in 1982. The water, sediment and submergent vegetation compartments were sampled biweekly. The runoff component was sampled when precipitation was sufficient to produce surface flow.

The parameters measured for the runoff and wetland water compartment were: (1) conductivity, (2) pH, (3) nitrate, (4) nitrite, (5) ammonia, (6) ortho-phosphate, (7) total phosphate and (8) potassium. Additionally, the temperature is measured for the water compartment.

Measurements of the sediment compartment include (1) nitrate + nitrite, (2) ammonia, (3) Kjeldahl-Nitrogen, (4) exchangeable phosphorus, (5) exchangeable potassium and (6) organic carbon. Since the sediments are very high in organic matter content, it was theorized that a measure

of the organic phosphorus would provide a good estimate of total phosphorus in the compartment. Thus, 1 gm sediment samples were ashed and analyzed for phosphorus. This estimate of total phosphorus is six to nine times greater than the measurement of exchangeable phosphorus.

Decomposition of *Typh* litter has been followed for a period of one year. Nylon mesh bags containing *Typh* leaves were placed in the water compartment during October 1981. Replicate litter bags have been collected throughout the year to determine loss in weight and change in chemical composition. Total nitrogen, phosphorus and potassium have been measured on all litter decomposition samples.

Submergent vegetation was sampled at biweekly intervals throughout the growing season to determine biomass and chemical composition. Biomass below and above the substrate was determined. Chemical analyses were restricted to total nitrogen, phosphorus and potassium. Sample area was 1/4 m^2 and was replicated six times on each wetland site. The dominant submergent genera contributing to the biomass were *Potamogeton*, *Ceratophyllum*, *Lemna*, *Chara*, and *Meriophyllum*.

Water samples from both sites have been collected for analysis of selected 2, 4-D metabolites.

B. Publications:

None.

C. Project Status:

The project is completed. A completion report is in progress.

D. Application of Research Results:

Agencies that are responsible for wetland management, including the U.S. Fish and Wildlife Service and the Minnesota Department of Natural Resources, are interested in the study. The data will provide more information about the structure and function of wetland ecosystems.

E. Work Remaining and Progress Contemplated During Next Year:

All field data has been collected. Some chemical analyses are incomplete, but will be finished in the near future. The major task remaining is to analyze and interpret the data.

OWRT Project No.: A-045-Minn

Project Title: Maximum Hydraulic and Nutrient Loading Rates of Septage to Soils

Agreement No.: 14-34-0001-2125

FCCSET Research Category: V-G

Name and Location of University Where Project is Being Carried Out: University of Minnesota, St. Paul, Minnesota

Project Began: October 1, 1980

Scheduled Completion: September 30, 1983

Principal Investigator	Degree	Discipline
Charles J. Clanton	M.S.	Agricultural Engineering
Roger E. Machmeier	Ph.D.	Agricultural Engineering
James L. Anderson	Ph.D.	Soil Science

Student Assistants	Degree	Discipline or Academic Background
Dana Danes	Undergrad	Pre-veterinarian Medicine
Martha Kennedy	Undergrad	Biology

A. Research Project Accomplishments:

The septage application rates of 1120 and 1500 kg per hectare of nitrogen resulted in increased concentrations of nitrates in the soil water for a Hubbard sandy loam, Waukegan silt loam and Lester clay loam. This indicates that the application rates utilized in this study were above the maximum rate that can be utilized by the three soils studied. This study is continuing with reduced application rates in order to determine a maximum application rate.

The first year's results indicate that soil type, application rates or soil depth did not result in a significant difference in total Kjeldahl nitrogen, ammonia, fecal streptococcus and fecal coliforms in the soil water samples. However, the nitrate concentrations were significantly different between the soils, application rates and soil depths. For the Hubbard sandy loam, rainfall had a larger effect on nitrate concentrations and movement within the soil profile than for the Waukegan silt loam or Lester clay loam. On the Waukegan silt loam and Lester clay loam there was relatively little change in the nitrate concentration in the soil profile during the period that septage was applied twice a week.

After the design loading was applied to the soil and no further applications made (week 15), there was a sharp increase in nitrate concentrations in the soil profile. This probably resulted from a change in the surface layer from an anaerobic to an aerobic condition resulting in nitrification and subsequent movement of nitrates through the profile following a rainfall event.

The second year's results with no additional septage application indicate a significant difference in nitrates and total Kjeldahl nitrogen between the soils, application rates, and soil depths. Generally, the nitrate concentrations in the Hubbard sandy loam and Waukegan silt loam were less than the first year, but the concentration in the Lester clay loam was higher than the first year. This indicates that nitrification and nitrate movement in the Lester clay loam is slower than the other two soils.

B. Publications:

Clanton, C.J., R. E. Machmeier, J.L. Anderson and M.J. Hansel. Maximum Application Rates for Land Treatment of Septage--Progress Report. ASAE Paper No. 81-2063. 1981.

Clanton, C.J, J.L. Anderson, R.E. Machmeier, M.J. Hansel. Maximum Loading Rates of Septage to Soils--Progress Report. Proceedings of the Third National Symposium on Individual and Small Community Sewage Treatment. 1981.

C. Project Status:

The project will continue until September 30, 1983 provided that funding is available.

D. Application of Research Results:

The Minnesota Pollution Control Agency will be able to develop guidelines for land application of septage and related wastewaters to be used throughout the state on various soil textures. In addition, there have been several requests from other state environmental or pollution agencies about our research findings to be compared with their research results and recommendations.

Consulting and design engineers will be able to utilize the information for planning land application systems. County officials will be able to utilize the information for county zoning and land use planning. And finally, septage haulers will be able to utilize the information by providing them with alternatives to delivery of the septage to the municipal treatment plants.

E. Work Remaining and Progress Contemplated Next Year:

The data collected during the summer of 1982 is currently being analyzed. This data will be compared with the first and second year's results. The intent will be to monitor the soil water for nitrates and other pollutants during 1983 with no additional application of septage.

OWRT Project No.: A-046-Minn

Project title: Low Energy Filtration Using Bouyant Media Filtration

Agreement No.: 14-34-0001-2125

Name and Location of University Where Project is Being Carried Out: University of Minnesota, Department of Civil Engineering, Minneapolis, Minnesota.

Project Began: March 1, 1982 Scheduled Completion: September 30, 1983

Principal Investigator	Degree	Discipline
Michael J. Semmens	Ph.D.	Environmental Engineering

Student Assistants	Degree	Discipline
Yuan Ming Tang	M.S.	Environmental Engineering

A. Research Project Accomplishments:

Since the bouyant media filtration project was initiated in February 1982, the design and construction of a test filter has been completed and preliminary testing of the filter is underway.

The filter design is illustrated in Figure 1 and using this type of pilot plant the hydraulic characteristics of the bouyant media have been studied. Headloss development has been evaluated as a function of temperature, media size, and flowrate. These studies have confirmed that very low headlosses are incurred at design loadings of between 2 and 5 gpm/ft^2 (4.9 - 12.2 m/h) which are typical of practice.

The effectiveness of the filter for turbidity removal under different operating conditions is currently being evaluated. On line surface scatter turbidimeters are employed to monitor the breakthrough of turbidity as a function of time. Turbidity and headloss development are measured at 15 cm depth intervals in the filter to identify where and how solids capture is taking place. To eliminate the difficulties of interpreting data from real wastewaters in which the influent quality may vary from test to test, a system has been designed to provide a constant quality of influent water. A clay is blended in metered quantities with tap water and the resulting suspension is flocculated with an inorganic coagulant such as $Al_2(SO_4)_3 \cdot 18H_2O$. The slurry is then pumped to the filter.

With this design a known solids load can be applied to the filter reproducibly.

It is too early in the project to draw conclusions from the results obtained.

B. Publications:

None.

C. Project Status:

The project is in progress and will be completed in September 1983.

D. Application of Research Results:

The results of this research project will identify the merits of using bouyant media filtration compared with conventional dual media filtration that is commonly employed in water and wastewater treatment practice. It will also provide information on the best operating strategy for bouyant media filtration to minimize the energy losses commonly incurred in the filtration process.

E. Work Remaining and Progress Contemplated During Next Year:

There are many control variables that must be considered in the design of a bouyant media filter. These include media size and depth, flowrate, backwash frequency, backwash rate and time. Studies to be conducted in the next year will identify the influence of these parameters on filter operation and performance. The data collected will be analysed by mathematical programming techniques to identify alternative operating strategies for different objectives.

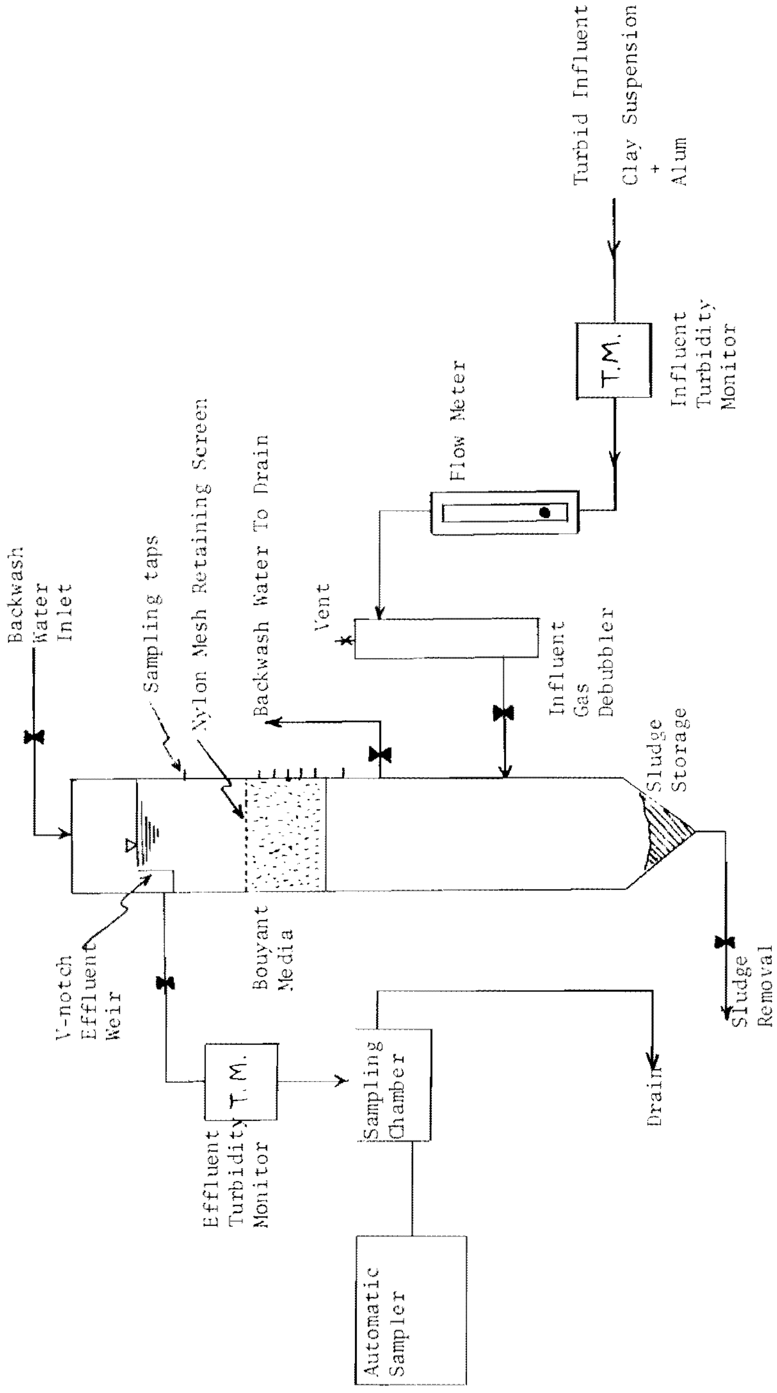

Figure 1 A schematic diagram depicting the 15 cm diameter test filter apparatus designed to evaluate filter performance under varying operating conditions.

OWRT Project No.: A-047-Minn

Project Title: Developing water use efficiency for crops (drought hardening for water conservation).

Agreement No.: 14-34-0001-2125

Name and Location of University Where Project is Being Carried Out: University of Minnesota, Horticultural Science and Landscape Architecture, St. Paul, Minnesota.

Project Began: March 1, 1982 Scheduled Completion: September 30, 1983

Principal Investigator	Degree	Discipline
Ok Young Lee-Stadelmann	Ph.D.	Plant Physiology
Eduard J. Stadelmann	Ph.D.	Plant Physiology

Student Assistants	Degree	Discipline or Academic Background
Denise Knuth	Undergrad	Biology/Forestry

A. Research Project Accomplishments:

Pisum sativum plants were grown under controlled environment. To induce drought tolerance water was withheld for 17 days during early vegetative growth, beginning the 7th day after planting. After 17 days of water stress leaf water potential reached about -10 bar (without wilting of the plant) and plants were rewatered. Ψ_s values were derived by analyzing pressure - water volume relations obtained by the pressure chamber technique. The osmotic potential of leaf palisade cells was determined by the incipient plasmolysis method. The osmotic potentials of the stress preconditioned (hardened) leaves were compared with the osmotic potential of the controls. The plants which were not used for this evaluation were transferred to the green house and brought to pod maturity to test productivity.

Although the data are not completely analyzed our preliminary results indicate that osmotic adjustment is taking place by the stress treatment; the osmotic potential of leaves of the stressed plants was consistently lower than the corresponding control value. The osmotic potentials were determined 3 days and 10 days after rewatering and were in both cases lower for the stressed plants. The recovery of the turgor potential, however, was observed only after 10 days of rewatering.

A formula was developed which allows to calculate the volumetric elastic modulus of the leaf from the pressure - volume relation. This formula will allow the indepth analysis of the differences in turgor potential recovery and relate this parameter to cell wall elasticity.

B. Publications:

None.

C. Project Status:

The project is in the first year and will continue for two more years.

D. Application of Research Results:

The results are expected to become a basis for developing methods to reduce water requirements of crop plants by induction of drought hardening. Furthermore, the results will be of use in establishing irrigation schedules for specific crops. The most important result of this study, however, will be the advancement of the understanding of drought adaptation of crop plants which will eventually allow optimization of water needs and productivity.

E. Work Remaining and Progress Contemplated During Next Year:

The experimental data will be evaluated and osmotic parameters such as osmotic potential and volumetric elastic modulus will be calculated and related to the stress history of the plants.

Different degrees of stress treatments will be tested and related to osmotic potential and productivity.

MATCHING GRANT PROGRAM

NARRATIVE PROGRESS REPORTS

Annual Report -- Title I Projects

OWRT Project No.: B-158-Minn

Agreement No.: 14-34-0001-1236

Project Title: Increasing Economic Efficiency of Water Use for Irrigation in the Upper Midwest

FCCSET Research Category: IV-B

Name and Location of University Where Project is Being Carried Out: University of Minnesota, St. Paul, Minnesota

Project Began: October 1, 1980 Scheduled Completion: September 30, 1983

Principal Investigator	Degree	Discipline
Vernon R. Eidman	Ph.D.	Agricultural and Applied Economics
Craig C. Shaeffer	Ph.D.	Agronomy

Student Assistants	Degree	Discipline or Academic Background
Paul R. Carter	M.S	Agronomy
David J. Nielson	B.S.	Agricultural Economics
Darrell Bosch	M.S.	Agricultural Economics

A. Research Project Accomplishments:

Accomplishments during the second year of this project can be summarized under three headings: Validation of Crop Models; Evaluation of Irrigation Strategies for Soybeans; and Field Trials to Generate Data for Crop Model Development and Validation.

1. Validation of Crop Models

Initial efforts to select a crop simulation model for the project focused on models by R. H. Shaw (Shaw 63), R.J. Hanks (Regetta and Hanks, 73), and R. W. Hill (Hill and Johnson, 1978). The third model, referred to as Hill's model in this report, has been selected to model corn and soybean yield response to soil water levels over the growing season. It was selected in preference to the other models because the Hill model: (1) more completely models the phenology of crop growth which reduces the need to provide input data on stage of plant growth, (2) includes several alternative methods of estimating daily evapotranspiration which can be used, (3) considers the total seasonal evapotranspiration which may be important in explaining low yields resulting from late planting or cool growing seasons (4) considers the effect of lodging due to excess moisture during vegetation stages of crop growth and (5) provides a better fit of the observed yield data than either of the other two models.

Validation efforts during the second year were limited primarily to the Lamberton area of Minnesota. This area was selected because it has the largest amount of data that can be used for validation of crop models. It is also centrally located in Southwestern Minnesota, an area in which crop yields are frequently limited by moisture.

Validation of the Hill model for both corn and soybeans consisted of three stages. First, the growth calendar predicted by the model was compared to the available data from field trials at Lamberton to determine how accurately the model predicted the number of days required for each stage of plant development. The second validation stage compared predicted to actual soil water measurements. The final validation stage compared yield predictions produced by the model with actual yields.

Limited data was available to validate the model's ability to predict crop growth stages. Experimental data at Lamberton used for validation included maturity dates for soybeans in 1973-1981 and silking dates for corn for 1973 and 1980. The observed maturity for soybeans occurred 2 to 11 days after predicted maturity, but the deviation exceeded 7 days in only 2 of the 9 years. The model predicted the silking date for corn accurately in 1973, but predicted a silking date 5 days before actual silking for 1980. Furthermore, the predicted crop development appeared reasonable given the field notes on crop development that are available. Based on this limited evidence and the seeming reasonableness of the overall corn and soybean calendar predicted by the model, the phenology prediction equation of the Hill model was considered appropriate.

Soil water predictions presented more of a problem than phenology predictions for Lamberton. Actual soil water measurements have been taken on the experimental corn plots at Lamberton at approximately two-week intervals throughout the growing season. Initial runs of the model overestimated the amount of water remaining in the soil during the season. This was true for the Jensen-Haise, Hargreaves, and Blaney-Criddle models of calculating potential evapotranspiration, with the Jensen-Haise overestimating soil water the most. The errors in estimating soil water could be due to incorrectly calculating the amount of water going into the soil, the amount of water leaving the soil, or both. It was hypothesized that the failure of the model to account for runoff and evapotranspiration losses was causing soil water estimates to be higher than actual readings. An equation was added to account for runoff, which made a slight improvement in the tendency of the model to over-estimate the soil water. Several modifications in the method to estimate the evapotranspiration throughout the growing season were considered. The most successful of these procedures is the Baker pan evaporation method. The Baker pan procedure involves multiplying the daily pan reading by the crop curve coefficient developed by Dr. Donald Baker of the University of Minnesota Soils Department.

The conclusion from work done with corn at Lamberton is that the Blaney-Criddle and Baker pan evapotranspiration methods track soil water more accurately than the other methods. Similar validation could not be run for soil water under soybeans because measured levels of soil water over time are not available for soybean experiments at Lamberton.

The Hill model was used to predict corn and soybean yields at Lamberton. The predicted yields calculated for each of two ETP methods are shown in Table 1 for 1973-1981. The Baker and Jensen-Haise ETP methods had the highest R^2 values and the Baker method had the smallest percentage errors in most years for soybeans. The conclusion from work done with corn at Lamberton is that the Blaney-Criddle and Baker pan evaporation methods have the closest association between actual and predicted yields as measured by R^2 values. Furthermore, these two methods neither tend to over or under predict corn yields. An analysis of the data by "wet" and "dry" years indicates the model tends to underpredict yields in years of average and above rainfall and overpredict yields in below average precipitation. The model's tendency to overpredict soil water combined with the model's definition of stress (soil water below 50 percent of capacity) indicates even small errors in soil water prediction can lead to large yield prediction errors.

The initial difficulty in validating yield data for corn and soybeans raised the question whether the problems in soil water estimation are the major problem in predicting yields. The program was modified to correct the predicted soil water level approximately every two weeks with the measured soil water readings. The results (Table 1) show that if soil water is tracked accurately the yield prediction for corn is also quite accurate. The predicted yield for corn was within 10 percent of the actual yield 6 years out of 7. The model underestimated acutal yield by 19 percent in 1977. Soil scientists at the University of Minnesota suggest the explanation may be that the drought in 1976 caused much residual nitrogen to be left in the soil which stimulated deeper than normal root growth in 1977. Soil water measurements under soybeans were unavailable at Lamberton, but the validation efforts suggest improving the model's ability to track soil water levels is also a logical starting point to improve the ability to predict soybean yields.

2. Evaluation of Irrigation Strategies for Soybeans

Alternative soybean irrigation strategies were evaluated on each of four soil types for the climatic conditions at Lamberton, Minnesota. The Hill model with the Jensen-Haise method of estimating ETP was used to predict soybean yields for each of 9 years (1973-1981) of historical weather conditions for each irrigation strategy on each of the four soil types. The resulting yield distributions were converted to net return distributions by multiplying the yields by the price of soybeans ($7.50 per bushel) and deducting the input costs (prices at 1982 levels). The net returns were calculated on an after-tax basis assuming a 30 percent marginal income tax rate. Stochastic dominance procedures were used to select the preferred irrigation strategies considering the decision maker's attitude toward risk (Zentner, et al.).

The empirical results on the ranking of irrigation strategies must be considered tentative in nature because further data is needed to more completely validate the Hill model for soybean yield production. However, the application of stochastic dominance provides a more power-

Table 1. Actual and Predicted Yields With Lamberton Experiment Station Data

	Corn				Soybeans		
		Predicted Yield	Predicted Yield With			Predicted Yield With	
Year	Actual Yield (Bu/Ac)	With Accurate Soil Water Data (Bu/Ac)	Blaney-Criddle (Bu/Ac)	Baker Pan Evaporation (Bu/Ac)	Actual Yield (Bu/Ac)	Jensen-Haise (Bu/Ac)	Baker Pan Evap. (Bu/Ac)
1981	96.7	92.4	79.8	105.9	49.0	34.5	36.8
1980	109.8	117.9	114.6	129.6	50.0	51.9	63.5
1979	148.0	148.0	138.2	141.0	51.1	60.9	60.6
1978	126.0	129.5	142.3	138.9	60.0	55.3	43.4
1977	160.3	129.4	118.3	119.1	51.9	44.5	41.8
1976	a/	58.9	66.0	59.5	a/	14.1	9.9
1975	91.3	96.9	108.6	109.7	39.6	36.4	37.3
1974	105.5	b/	107.5	100.8	27.1	31.6	29.3
1973	117.1	117.1	125.0	112.1	39.1	37.5	32.1

a/ 1976 was a drought year with very low yield levels. The actual yield for 1976 is not available.

b/ The available soil water data for 1974 could not be processed.

full approach in evaluating preferred irrigation strategies for alternative groups of irrigators.

Four soils representative of the wide range in available water holding capacity of cropland soils in Southwestern Minnesota were studied. They are a Hubbard soil (AWC = 3.30" in the top 60" of soil), a Dickinson soil (AWC = 4.90"), a Webster soil (AWC = 9.60") and a Nicollet soil (AWC = 13.40").

The results of three irrigation strategies studied are summarized here. They are: (1) unirrigated production, (2) the "naive rule" which assumes farmers are familiar with the water use requirements of soybeans but do not use soil water monitoring equipment; and (3) basing irrigation decisions on accurate soil water monitoring equipment. Several triggering levels by stage of plant growth for each of two application rates (.75 inches and 1.00 inches per application) were tested for Strategy 3 (Nielson, p. 44).

The analysis assumed recommended tillage, fertility and pesticide programs for the respective soils. Water application costs are based on operation of a non-towable, ten-tower, center pivot irrigation system covering 130 acres. The water source is a 150 foot well with 50 feet of lift producing 800 gallons per minute. An electric motor is the assumed power unit.

Optimal irrigation strategies for each soil type were selected by level of risk aversion (preference) using stochastic dominance with respect to a function (Nielson, pp. 12-20). The Arrow-Pratt coefficient of absolute risk aversion is the measure of risk aversion or preference used in the analysis. Conceptually the coefficient can range from $-\infty$ to $+\infty$, with negative, zero, and positive values indicating risk preference, risk neutrality and risk aversion, respectively. The risk aversion intervals used in the analysis of irrigation strategies were based on estimates prepared for southern Minnesota farmers as part of another study (Wilson). The study by Wilson concluded that the majority of producers have an Arrow-Pratt coefficient that falls between -.0005 and .001. This risk aversion-preference range was divided into subintervals of -.0005 to -.0001, -.0001 to .0001, .0001 to .0003, and .0003 to .001.

The after-tax net returns for each of the three strategies and each soil are presented on a per acre basis in Tables 2 through 5. (Only the preferred triggering level and application rate is shown for the third strategy in this summary). The rankings of the three strategies are presented by level of risk aversion. A ranking of 1 indicates that the corresponding strategy was preferred to the strategies with lower rankings (i.e., 2 or 3). Strategies with identical rankings could not be ordered in relation to each other for the risk aversion interval indicated.

A comparison of the distributions and their summary statistics (mean, $\overline{X}$, and standard deviation, S) may help in interpreting the

Table 2. After-tax Net Returns ($/acre) to Alternative Irrigation Scheduling Strategies for Soybean Production on the Hubbard Soil

	Use of Monitoring Equipment Var Trig Level 1.0" Applications	"Naive Rule" .75" Applications	Unirrigated
	51.64	39.14	25.24
	80.96	63.51	27.76
	116.84	109.11	55.52
	117.74	109.19	59.62
	141.61	123.75	155.02
	143.08	134.05	156.74
	148.47	147.75	160.48
	150.31	150.03	160.58
	157.92	153.28	239.33
$\overline{x}$ =	123.18	114.42	115.16
S =	33.82	37.53	71.25

Preference Rankings as determined by Meyer's Criterion

risk aversion interval (Arrow-Pratt coefficient)			
-.0005 to .0003	1	3	2
.0003 to .001	1	2	2

Table 3. After-tax Net Returns ($/acre) to Alternative Irrigation Scheduling Strategies for Soybean Production on Dickinson Soils

	Use of Monitoring Equipment 1.0" Applications	"Naive Rule" .75" Applications	Unirrigated
	50.32	44.67	50.44
	84.58	67.20	53.06
	118.23	110.95	80.68
	118.65	111.03	96.79
	155.53	138.45	161.84
	158.99	142.43	175.47
	163.49	149.59	179.42
	168.50	151.43	180.85
	171.91	155.12	192.65
$\bar{x}$ =	132.25	118.98	130.13
S =	40.12	37.35	55.60

Preference Rankings as determined by Meyer's Criterion

Risk aversion interval (Arrow-Pratt coefficient)			
-.0005 to .001	1	3	2

Table 4. After-tax Net Returns ($/acre) to Alternative Scheduling Strategies for Soybean Production on the Webster Soil

	Use of Monitoring Equipment .75" Applications	"Naive Rule" 1.0" Applications	Unirrigated
	46.20	34.06	100.92
	67.73	56.90	123.96
	107.47	101.82	135.57
	110.56	102.76	135.72
	132.90	115.52	150.16
	138.08	134.28	188.28
	140.58	138.12	202.35
	146.11	140.46	223.35
	147.96	142.79	226.92
$\bar{x}$ =	114.96	107.41	165.25
S =	34.38	36.60	43.34

Preference Rankings as determined by Meyer's Criterion

Risk aversion interval (Arrow-Pratt coefficient)			
-.0005 to .001	2	3	1

Table 5. After-tax Net Returns ($/acre) to Alternative Irrigation Scheduling Strategies for Soybean Production on the Nicollet Soil

	Use of Monitoring Equipment 1.0" Applications	"Naive Rule" 1.0" Applications	Unirrigated
	48.08	34.06	127.53
	70.61	56.15	150.00
	111.16	101.82	176.62
	112.10	102.76	187.02
	128.77	129.01	188.28
	138.12	138.12	190.69
	147.47	138.12	226.92
	149.80	140.46	226.92
	149.80	142.79	226.92
$\bar{x}$ =	117.32	109.25	188.99
S =	34.36	37.53	32.96

risk aversion interval (Arrow-Pratt coefficient)	Preference Rankings as determined by Meyer's Criterion		
-.0005 to .001	2	3	1

results. On soils, with a relatively low water holding capacity, such as the Hubbard, irrigation tends to increase yields and returns enough to more than pay the additional costs of owning and operating the irrigation system and the other increases in production costs associated with higher yields. On these soils with a low water holding capacity, irrigation strategies tend to have a higher expected return and a lower standard deviation than unirrigated production. As the water holding capacity of the soil increases, irrigated strategies provide smaller increases in yield and gross income. However, irrigation on these soils requires costs associated with the investment in the system as well as some irrigation operating costs and other increased production costs. For this reason, the Nicollet soil, which has the highest available water holding capacity, has a lower expected return and a larger standard deviation for irrigated strategies than unirrigated production. The results for the Dickinson and Webster soils fall in between the results for the Hubbard and Nicollet soils.

Several major points can be summarized from the stochastic dominance ranking of these strategies for each of the four soils. (1) The unirrigated strategy was preferred to both irrigation strategies on the two soils having relatively high water holding capacities (i.e., the Nicollet and Webster soils). This suggests producers on these soils having a risk aversion coefficient in the specified interval should not be advised to irrigate soybeans. (2) The naive rune (which represents the level of efficiency irrigators are likely to achieve without soil monitoring equipment) was not preferred to unirrigated production on any of the soils, although the shift to no preference between unirrigated and the naive rule on Hubbard soils for the risk aversion interval .0003 to .001 suggests more risk averse irrigators might prefer the naive rule on these soils. (3) The higher level of irrigation efficiency achieved with monitoring equipment makes this irrigation strategy preferable to the naive rule on all four soils. It is also preferable to unirrigated production on the soils with lower water holding capacities (i.e., Hubbard and Dickinson).

It is useful to extend the analysis from an acre to an enterprise level. Strategies at the enterprise level involve larger sums of after-tax net returns and the choices may differ from those made when the analysis is carried out on a per acre basis. Thus, the analysis was also conducted for an enterprise level of 130 acres, the most common size of irrigation enterprise in southern Minnesota using a center pivot system.

Each element of the net returns distributions was mulitplied by 130 acres to develop the net returns distribution for the enterprise. Stochastic dominance was used to select the preferred strategies for the 130-acre enterprise. The resulting rankings are shown in Table 6.

The difference by subintervals of risk aversion are accentuated at the enterprise level. On the Hubbard soil, the unirrigated strategy was preferred to the irrigated strategies for the risk preferring agents in the -.0005 to -.0001 risk aversion subinterval, while risk neutral irrigators (those within the -.0001 to .0001 risk aversion sub-

Table 6. Stochastic Dominance Rankings of Alternative Irrigation Strategies for Varying Soil Types and Risk Aversion Intervals on a 130-acre Enterprise Basis

	Alternative Irrigation Scheduling Strategies		
Risk Aversion Interval (Arrow-Pratt coefficients)	Use of Monitoring Equipment	Naive Rule	Unirri-gated
Hubbard Soil			
-.0005 to -.0001	2	3	1
-.0001 to .0001	1	2	*
.0001 to .0003	1	2	3
.0003 to .001	1	2	3
Dickinson Soil			
-.0005 to -.0001	2	3	1
-.0001 to .0001	1	3	1
.0001 to .0003	1	2	2
.0003 to .001	1	2	3
Webster Soil			
-.0005 to -.0001	2	3	1
-.0001 to .0001	2	3	1
.0001 to .0003	2	3	1
.0003 to .001	2	3	1
Nicollet Soil			
-.0005 to -.0001	2	3	1
-.0001 to .0001	2	3	1
.0001 to .0003	2	3	1
.0003 to .001	2	3	1

Note: *indicates that producers are indifferent between unirrigated and any of the other strategies.

interval) were indifferent between each of the irrigated strategies and the unirrigated strategy. The risk averse irrigators (with Arrow-Pratt risk aversion coefficients between .0001 and .001) prefer the irrigated strategies to the unirrigated strategy for the Hubbard soil.

For the Dickinson soil the unirrigated strategy was preferred to irrigated strategies for the most risk preferring subinterval, but as risk aversion increased, it became less clearly preferred. For the most risk averse subgroup included here, .0003 to .001 in terms of the Arrow-Pratt coefficient, the soil monitoring strategy was preferred to no irrigation and irrigators would be indifferent between the Naive Rule and unirrigated strategies.

For both the Webster and Nicollet soils, unirrigated production was preferred among all agents in the -.0005 to .001 risk aversion interval to the irrigated strategies considered. However, the strategy with monitoring equipment was preferred to the Naive Rule in every instance.

3. Field Research

The second year of field research on soybean and alfalfa response to variable irrigation levels at Becker, Minnesota, is nearing completion. The 1982 results for both crops will be included in the next report. A yield summary for the 1981 experiments was included in the last annual report. A more detailed analysis of the 1981 alfalfa data is presented here.

Irrigation was applied to 4.6- x 4.6-m plots within an established alfalfa stand. Four irrigation treatments, arranged in a randomized complete block design with three replicates, were initiated 26 May and continued until 9 October 1981. These treatments were planned to provide a range in soil water availability and were designated as follows:

H = high irrigation; irrigation to bring root zone extractable soil water (ESW) levels within approximately 15 percent of field capacity at 35 percent ESW depletion;

MH = medium high irrigation; irrigation same time as H with 66 percent as much water applied;

ML = medium low irrigation; irrigation same time as H with 33 percent as much water applied;

U = unirrigated; rainfall only.

Irrigation dates and amounts are shown in Fig. 1a. Daily maximum air temperature, rainfall and evaporation from a USWB Class A pan were obtained from a weather station located 800 m from the plot area (Figs. 1a-1c). Volumetric soil water content (θ_v) was monitored throughout the season at 0.15-, 0130-, 0.45-, 0.60-, 0.90-, 1.20-, 1.50- and 1.90-m depths using a neutron scattering devide (Model 503, Campbell

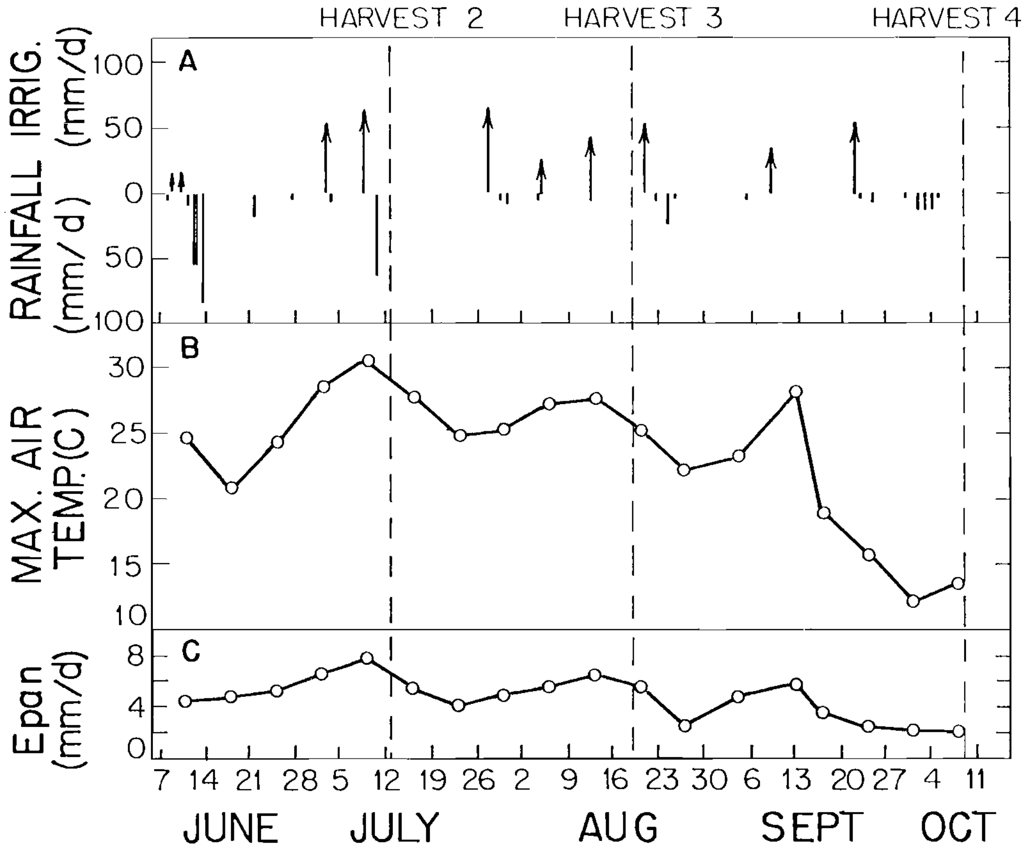

Figure 1. Rainfall and irrigation water, weekly average maximum air temperature, and weekly average pan evaporation during 1981.

Pacific Nuclear, Pacheco, Calif.)[3] which was field calibrated. Extractable soil water was determined as water held between field capacity (206 mm) and maximum depletion by severely droughted plants 0.026 m) to a depth of 2.1 m which was the most active water extraction zone (Figs. 1d and 2).

Average midday plant water potential (ψ_{mp}) was estimated throughout the season with a pressure chamber by sampling two plants from each plot in rapid succession during cloud-free periods from 1200 to 1600. Dry matter yield was measured in 1981 on 8 June (Harvest 1), 13 July (Harvest 2), 19 August (Harvest 3), and 9 October (Harvest 4) when alfalfa reached first flower. Forage was removed from 0.30- x 0.36-m areas in each plot to a 7-mm height and dried. Forage quality analyses were conducted on Harvests 1 and 3 which represented a range in environmental and soil moisture growth conditions. These analyses included crude protein (CP) determined by the Kjeldahl procedure and in vitro dry matter disappearance (IVDMD) concentration measured by the two-stage direct acidification method.

Water use during various time periods was estimated using the equation: $ET = I + R + D + \Delta S$ where ET is water use, I is irrigation, R is rainfall, and ΔS is the change in stored soil moisture for the time considered. Water use was only calculated during low-rainfall periods (i.e., end of second growth cycle and for the entire third and fourth cycles) (Fig. 1a) when deep drainage (D) was expected to be minimal. Soil water flux calculations using Darcy's law substantiated that negligible downward water movement occurred from 1.50 to 1.90 m during this time period. Water-use efficiency was calculated for Harvests 3 and 4 since complete ET measurements occurred during these growth cycles.

Soil and Plant Water Status

Soil moisture differences between irrigation treatments were comparatively small during the first growth cycle; thus discussion will focus on the second, third and fourth growth periods. Irrigation and rainfall maintained ESW of the high irrigation (H) treatment above 0.11 m (40 percent ESW depletion) throughout most of the season (Fig. 1d). Medium high (MH) and medium low (ML) treatments had approximately 0.03 and 0.06 m less ESW, respectively, than the H treatment during early July, August, September and early October. Extractable soil water levels for the unirrigated treatment (U) were 0.04 to 0.13 m below those of the H treatment throughout the season and decreased continuously, except after occasional rainfall, until 21 September when all ESW was depleted.

Soil water depletion occurred to the 1.90-m depth for all treatments from 24 June to 28 September (Fig. 2). Greatest depletions occurred for the U treatment which almost completely depleted θ_v to the 1.50-m depth by 22 August (Fig. 2c). By 28 September, alfalfa in the ML treatment removed most of the θ_v from 0.90- to 1.90-m depths (Fig. 2d).

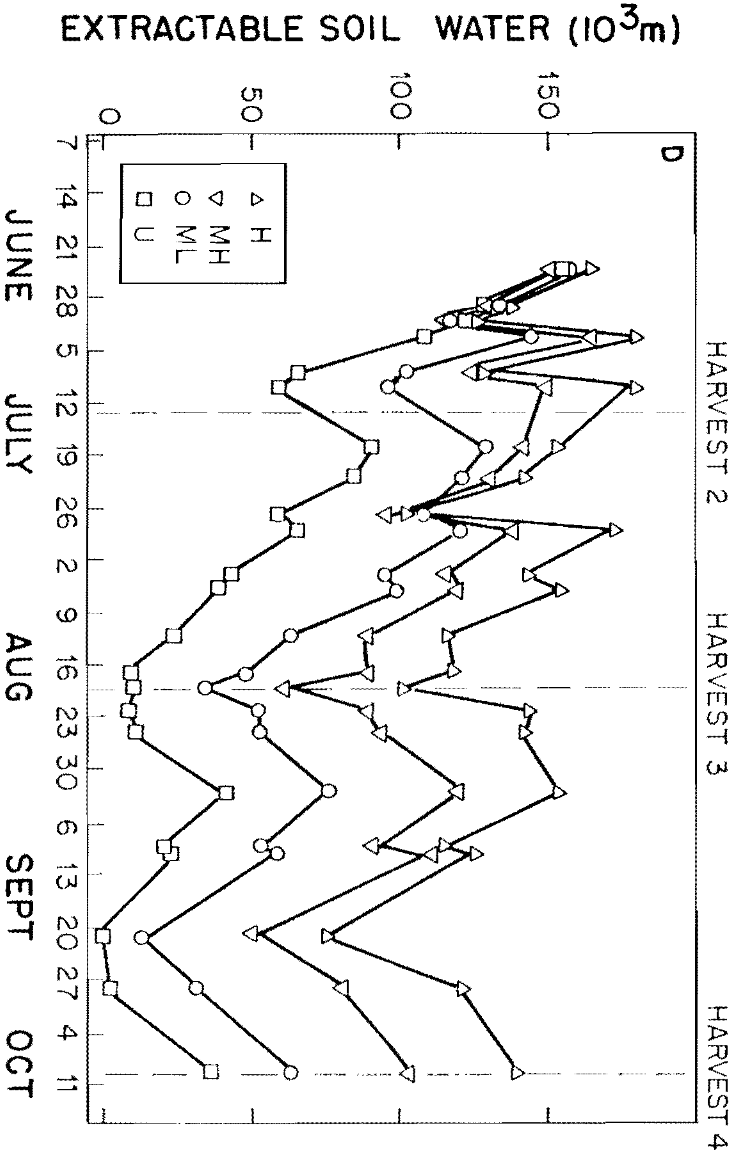

Figure 1d. Extractable soil water for four alfalfa irrigation treatments during 1981.

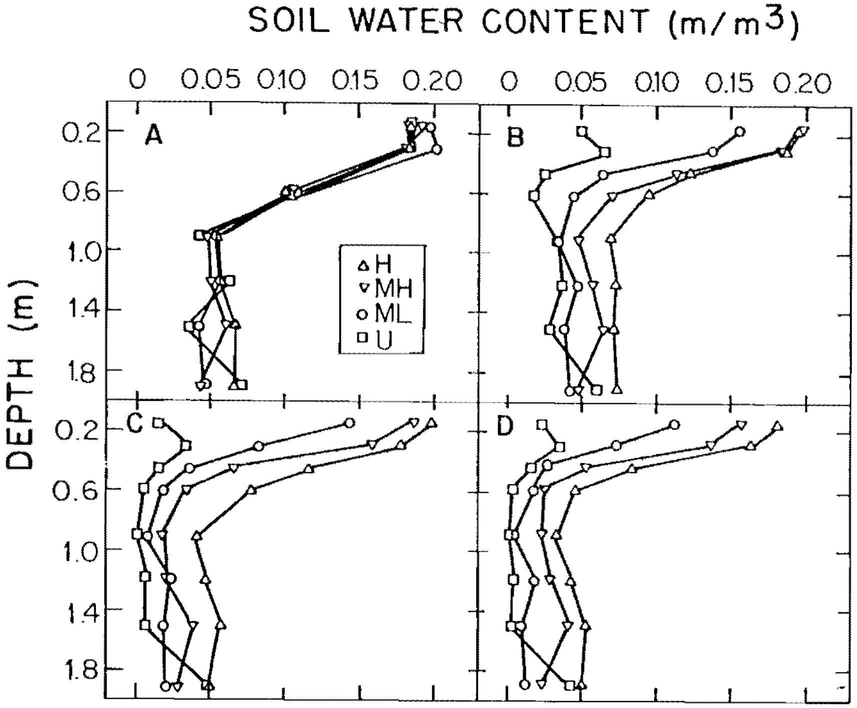

Figure 2. Volumetric soil moisture contents at several depths for four irrigation treatments during 1981.

Soil water contents for the MH treatment were depleted substantially below H treatment levels especially in the 0.45- to 1.90-m region (Fig. 2c).

A consistent climatic pattern was observed during the 1981 season in which rainfall occurred at or immediately after each harvest with low rainfall between harvests (Fig. 1a). Daily maximum air temperature and pan evaporation (Epan) were comparatively low near harvest and increased during the second, third, and early fourth growth intervals (Figs. 1b and 1c). These patterns combined with increased LAI during regrowth and possible phenological increases in plant resistance resulted in a general decline in alfalfa ψ_{mp} in the H treatment during the second and third growth cycles and a range in ψ_{mp} from about -0.7 to -1.3 MPa. The MH treatment maintained ψ_{mp}'s within 0.1 to 0.2 MPa of the H regime in each regrowth period. Although the soil had a very low water holding capacity, alfalfa in the MH treatment evidently obtained sufficient water from the 1.90-m profile to maintain plant hydration. Substantial reductions in ψ_{mp} did not occur until about 50 percent of the ESW was removed, after which a sharp drop in ψ_{mp} occurred (Fig. 3). The MH treatment had soil moisture levels at or above this threshold throughout most of the season (Fig. 1d).

Alfalfa in the ML and U treatments began each regrowth period with a favorable plant water status, but as soil water was depleted during regrowth, plant water stresses developed. By Harvest 2, alfalfa receiving ML and U treatments had ψ_{mp} values of -1.5 and -2.7 MPa, respectively; and ψ_{mp} had decreased to -2.5 (ML) and -4.0 (U) MPa by Harvest 3. The greatest plant water stress during the fourth growth cycle occurred on 21 September, but by harvest alfalfa ψ_{mp} for the ML treatment had recovered to -1.2 MPa and unirrigated alfalfa (U) ψ_{mp} to -2.1 MPa.

Forage Quality

No consistent relationship between alfalfa irrigation treatments and CP concentration occurred at Harvests 1 or 3 despite large differences in plant water status (Table 7). Crude protein concentration was similar for all treatments at Harvest 1. For Harvest 3, significant differences occurred in CP concentrations of high (H) and medium high (MH) irrigated alfalfa, despite small differences in plant water potential (ψ_{mp}) between these treatments. Since N concentrations generally increase under plant water stress for plants that do not fix N_2, the inconsistent responses to plant water deficits might be explained by variations in the N_2 fixation capabilities of alfalfa grown in different studies.

The in vitro digestible dry matter (IVDMD) concentration was similar for all treatments at Harvest 1, but alfalfa in the unirrigated treatment had a significantly greater IVDMD at Harvest 3 than irrigated treatments (Table 7). This increase was not associated with leaf:stem weight ratios since ratios were similar for all treatments at Harvest 3. Apparently this response only occurs under extreme plant water stress since IVDMD concentration in our experiment was unaffected until alfalfa ψ_{mp} dropped below -2.7 MPa (Table 7).

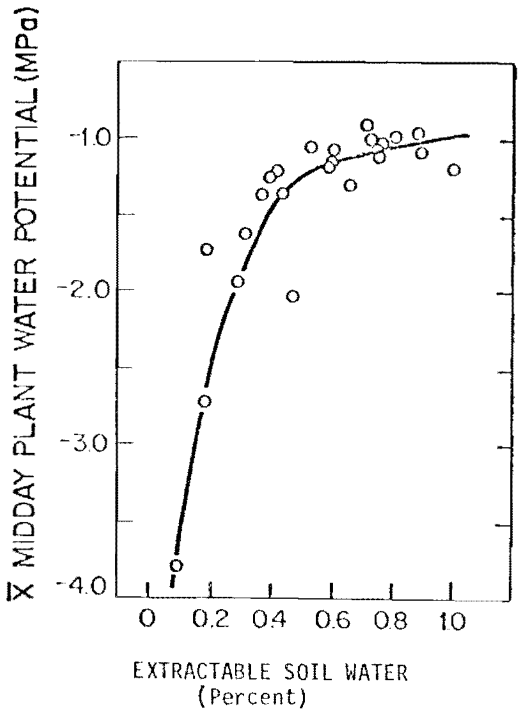

Figure 3. Relationship between mean alfalfa midday plant water potential averaged over 3 to 10 day periods, and % extractable soil water during growth cycles.

Table 7. Crude protein (CP) and in vitro dry matter disappearance (IVDMD) concentrations of alfalfa grown under four irrigation treatments at the first and third harvests.

Harvest	Irrigation treatment	CP	IVDMD	ψ_{mp} †
		%		MPa
1	High	19.3	62.9	-1.4
	Medium high	18.5	62.4	-1.9
	Medium low	18.1	62.4	-2.1
	Unirrigated	18.3	62.1	-2.7
BLSD‡		n.s.	n.s.	
3	High	19.0	58.6	-1.2
	Medium high	17.0	57.7	-1.4
	Medium low	17.7	58.4	-2.5
	Unirrigated	18.3	62.5	-4.0
BLSD		1.7	1.5	

† Midday plant water potential at harvest.

‡ Bayes L.S.D. (K = 100).

Water-Use Efficiency

Third harvest water use (ET) and water use efficiency (WUE) were similar for alfalfa grown under H and MH treatments (Table 8). Maintenance of ET and plant water status by depletion of soil water to lower levels than for alfalfa subjected to the H treatment enabled MH-treated alfalfa to produce forage yields for this harvest similar to the H treatment while using 32 percent less irrigation water. Water-use efficiency declined with reductions in ET for alfalfa in ML and U treatments since forage yield decreased more than ET under plant moisture stress.

Alfalfa subjected to irrigated treatments (H, MH, ML) had similar forage yields for Harvest 4, but ML-treated alfalfa used 23 and 41 percent less water than plants in MH or H treatments, respectively; thus having the greatest WUE for this harvest. As in Harvest 3, U-treated alfalfa had the lowest WUE. Cooler temperatures and fall dormancy responses resulted in a 50 percent decrease in forage yield, averaged over treatments, for Harvext 4 compared to Harvest 3 while averate ET was similar for the two harvests. This resulted in 36 percent less WUE for Harvest 4, than for Harvest 3. Therefore, on the basis of efficient water use, fall irrigation does not appear desirable.

Total forage yield for all four harvests averaged 100 percent greater for irrigated compared to unirrigated alfalfa (Table 9). The H and MH treatments had similar seasonal forage yields despite the application of 34 percent less irrigation water to MH than to the H treatment. The ML treatment produced 86 percent as much forage yield as the H treatment while requiring 68 percent less irrigation water.

Be extracting soil water to a greater extent, alfalfa grown with moderate irrigation applications produced forage yields equivalent to those obtained when irrigation maintained high soil water levels. Therefore, it appears that irrigation water could be used efficiently on coarse-textured soils by moderate water applications to alfalfa at 50 percent depletion of ESW, the apparent threshold for maintenance of favorable plant water status. Initiation of irrigations when plant measurements indicate soil water depletion to such a threshold may be a means of maximizing forage yields while conserving water resources.

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Table 8. Rainfall, irrigation water applied, soil water depletions, water usage, alfalfa forage yields and water-use efficiencies for four irrigation treatments during the third and fourth growth cycles.

Growth cycle	Irrigation treatment	Rain-fall	Irrigation water applied	Soil water depletion	Water use	Forage yield	Water use efficiency
		mm				$Mg\ ha^{-1}$	$Mg\ ha^{-1}\ mm^{-1}$
3	High	21	133	51	205	4.9	2.39×10^{-2}
	Medium high	21	91	82	194	4.8	2.47×10^{-2}
	Medium low	21	45	95	161	3.4	2.11×10^{-2}
	Unirrigated	21	0	80	101	1.4	1.39×10^{-2}
4	High	98	142	-37	203	2.5	1.23×10^{-2}
	Medium high	98	101	-43	156	2.2	1.41×10^{-2}
	Medium low	98	51	-29	120	2.1	1.74×10^{-2}
	Unirrigated	98	0	-25	73	0.7	0.96×10^{-2}

Table 9. Irrigation water applied, rainfall, total water application (irrigation + rainfall) and total alfalfa forage yields for four irrigation treatments.

Irrigation treatment	Irrigation water applied	Rainfall	Total water application	Total forage yield
	mm			$Mg\ ha^{-1}$
High	459	421	880	14.3
Medium high	305	421	726	14.8
Medium low	149	421	570	12.3
Unirrigated	---	421	421	6.8

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Wilson, Paul N. 1982. The Structural Determinants of the Swine Production Industry. Unpublished Ph.D. Dissertation, University of Minnesota, St. Paul.

Zentner, R.P., D.D. Green, T.L. Hickenbotham and V.R. Eidman. 1981. Ordinary and Generalized Stochastic Dominance: A Primer, Staff paper P81-27, Department of Agricultural and Applied Economics, University of Minnesota, St. Paul.

B. Publications

Carter, P.R. 1982. Response of Alfalfa to Soil Water Deficits. Ph.D. Thesis. University of Minnesota.

Nielson, David J. 1982. Evaluating Alternative Irrigation Scheduling Strategies for Soybeans in Minnesota: An Economic Analysis Employing Stochastic Dominance. Unpublished Plan B Paper. Department of Agricultural and Applied Economics, University of Minnesota.

Wilson, Paul N. and Vernon R. Eidman. 1981. The Economics of Irrigating Medium and Fine Textured Soils in Minnesota, Economic Report ER 81-8, Department of Agricultural and Applied Economics, University of Minnesota.

C. Project Status

The project will be continued during the next fiscal year.

D. Application of Research Results

The field trials and the results of the modeling work are being used to adjust alfafla and soybean irrigation recommendations. The corn model will be used during the next year to help evaluate the effect of interrupting electrical power supplies to irrigators during peak power use periods. The effects of interrupting power supplies on yields and net returns is of interest in developing contracts with irrigators under which power companies can interrupt service to reduce peak power use.

E. Work Remaining and Progress Contemplated During Next Year

The data on soil water levels and crop response to irrigation at Becker, Minnesota, will be used to validate the model for that location. Data on corn that has been developed under other research projects at Becker as well as the soybean and alfalfa work done under the grant will be used for the validation effort.

The corn and soybean models will be incorporated into a whole-farm planning model for the Lamberton area to conduct the work under Objectives 2, 3 and 4 of the project.

Alfalfa and soybean field trails will be continued at Becker. Corn will be planted and subjected to irrigation treatments outlined in the original proposal.

OWRT Project No.: B-161-Minn

Agreement No.: 14-34-0001-1237

Project Title: Mathematical Hydrologic Simulation of Critical Watersheds in Northeastern Minnesota

FCCSET Research Category: II-E

Name and Location of University Where Project is Being Carried Out: University of Minnesota, St. Paul, Minnesota

Project Began: October 1, 1980 Scheduled Completion: September 30, 1983

Principal Investigator	Degree	Discipline
C. Edward Bowers	M.S.	Civil Engineering

Student Assistants	Degree	Discipline or Academic Background
C. Teng	M.S.	Civil Engineering
Joel Toso	B.S.	Civil Engineering

A. Research Project Accomplishments:

The objective of this project is the fitting of two hydrologic, mathematical simulation models to selected watersheds in or adjacent to the Boundary Waters Canoe Area of Northeastern Minnesota. The models will be of value in monitoring the quantity and quality of streamflow in the area. The BWCA is a protected wilderness area with no roads or habitations. Due to the presence of taconite and copper-nickel ores adjacent to the area, there is the potential for pollution of the pristine water of the many lakes and streams in the area.

During the first two years of operation, the Streamflow Simulation and Reservoir Regulation Model (SSARR) was the primary model studied. The latest versions of other models RIVALL and NWSRFS both prepared by the National Weather Service were acquired but have not been operated.

The SSARR is a continuous synthesis hydrologic model with two modes of operation, (1) Split Basin and (2) Snow Band. The model has been fitted and operated with both modes. Input data includes physical data for the watersheds plus daily data on precipitation and temperature. In this study it has been fitted to the 1200 square-mile Kawishiwi River Basin, with 12 sub-watersheds. Parameters in the model were adjusted in test runs, each of 6 months to 1 year duration for selected past periods.

Figures 1 and 2 illustrate computed and observed flows of the Kawishiwi River near Winton. Figure 1 was a run during the model fitting phase; Figure 2 is a verification run for a 17-month period.

A comprehensive report on the fitting and verification of the SSARR Model has been completed and is ready for final typing.

Preliminary runs with the RIVALL Model have been completed. Detailed fitting is underway.

B. Publications

None.

C. Project Status

The project will continue for the next year (fiscal 1983).

D. Application of Research Results

The Minnesota Department of Natural Resources, the Minnesota Environmental Quality Board and the Minnesota River Forecast Center of the National Weather Service have indicated an interest in the results of this study. Preliminary results have been shown to the River Forecast Center.

E. Work Remaining and Progress Contemplated During Next Year

Further fitting of the RIVALL Model and the NWSRFS Model will be performed during the next fiscal year.

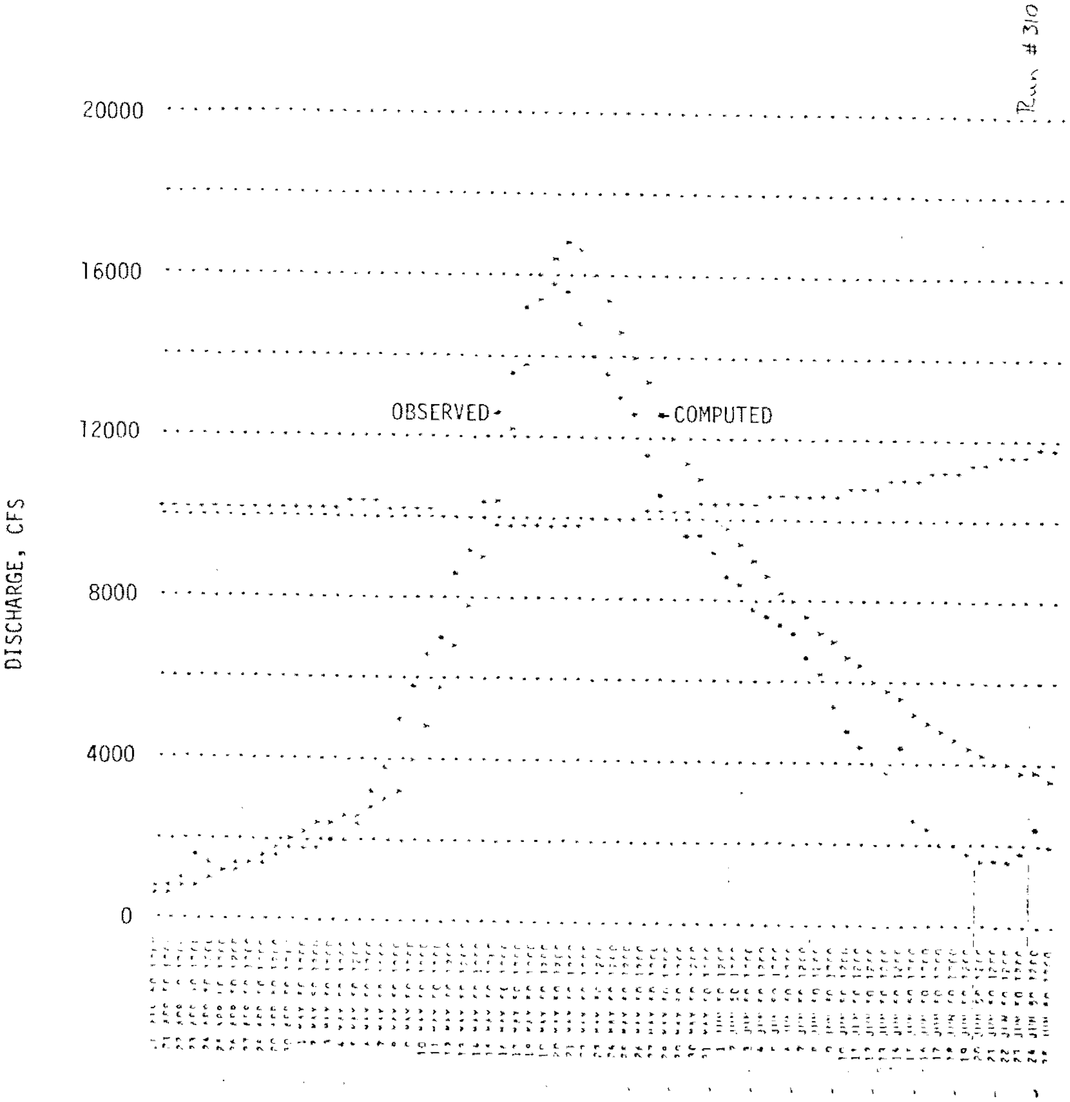

Figure 1

Observed and Computed Flow of Kawishiwi River Near Winton for Spring Flood of 1950

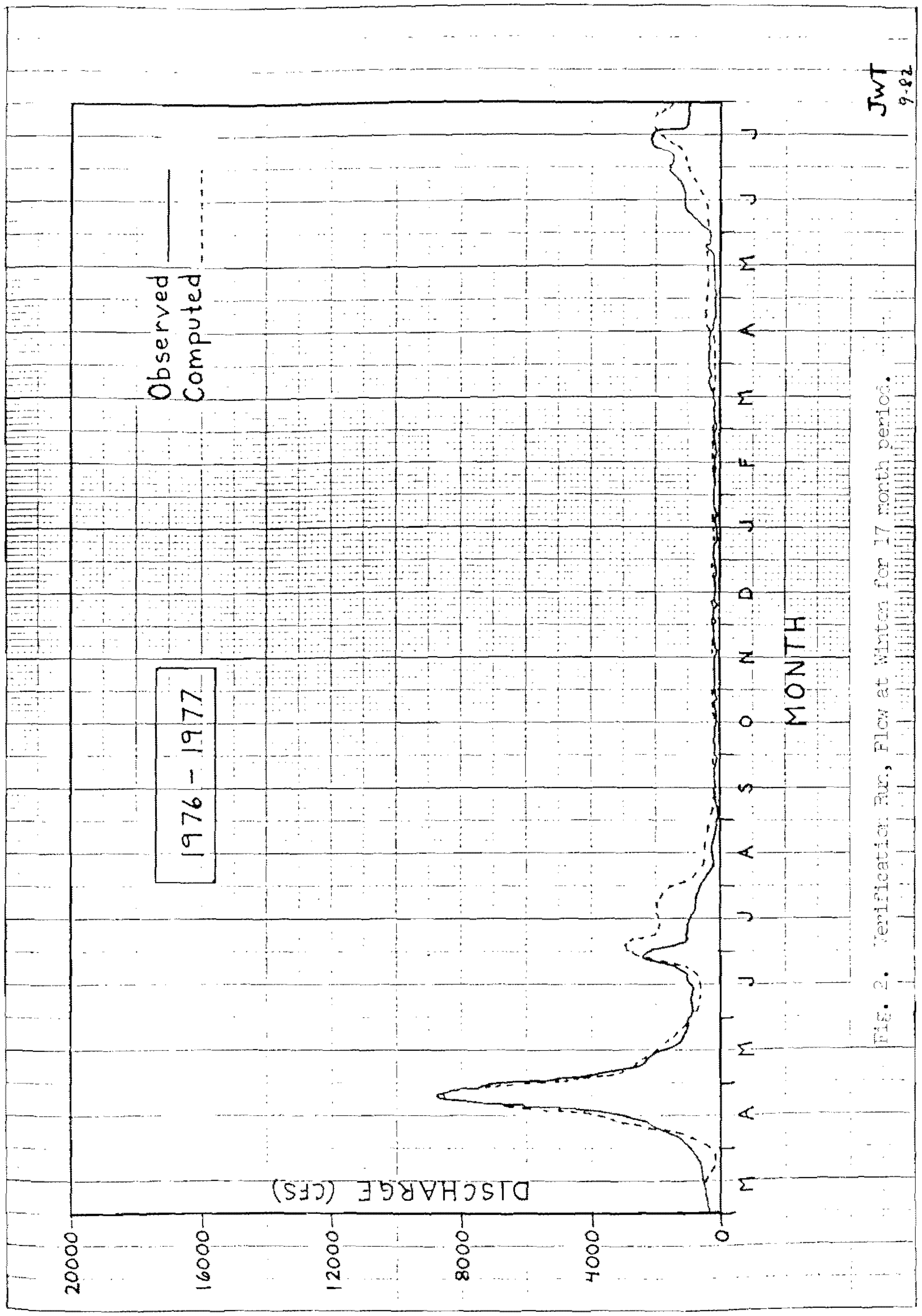

Fig. 2. Verification Run, Flow at Winton for 17 month period.

TECHNOLOGY TRANSFER PROGRAM

Publications of the Water Resources Research Center and Project-Related Reports

Blake, G. R. and E. Espointour. Seventeenth Annual Report, Water Resources Research Center. Water Resources Research Center, University of Minnesota. Bulletin No. 108. 1981.

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Clanton, C. J., R. E. Machmeier, J. L. Anderson and M. J. Hansel. Maximum Application Rates for Land Treatment of Septage--Progress Report. ASAE Paper No. 81-2063. 1981.

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Larson-Albers, C.E. The Impact of Wetlands and Drainage on Water Quality in an Agricultural Watershed in South Central, Minnesota. WRRC Report Number 3. Water Resources Research Center, University of Minnesota. 1982.

Nielson, D. J. Evaluating Alternative Irrigation Scheduling Strategies for Soybeans in Minnesota: An Economic Analysis Employing Stochastic Dominance. Unpublished Plan B Paper. Department of Agricultural and Applied Economics, University of Minnesota. 1982.

Wilson, P. N. and V. R. Eidman. The Economics of Irrigating Medium and Fine Textured Soils in Minnesota, Economic Report ER 81-8, Department of Agricultural and Applied Economics, University of Minnesota. 1981.

EDUCATION AND TRAINING PROGRAMS

Additional Water Resources Related Staff Members Added:

Dr. John Gulliver, Ph.D. Water Resources, Civil Engineering was added to replace retiring staff member.

Dr. David Bintz, Ph.D. Water Resources, Civil Engineering was added September 16, 1982.

ANNUAL REPORT - TRAINING AND EDUCATION ASPECTS OF THE WATER RESEARCH PROGRAM UNDER P.L. 88-379

University of Minnesota, Minneapolis, MN

A. Number of students receiving employment as research project or program assistants through the P.L. 88-379 program.

	Scientific Discipline of Student	Number
(1) Undergraduates	Agricultural Engineering	1
	Biology	4
	Biology/Forestry	1
	Pre-Veterinarian Medicine	1
(2) Master's Students	Agricultural Engineering	1
	Agricultural Economics	1
	Biology	1
	Civil Engineering	2
(3) Doctoral Students	Agronomy	1
	Agricultural Economics	1
	Environmental Engineering	1

(4) Postdoctoral Students

None

B. Employment status of majors in water-related fields who graduated during the school year ending about June and who received P.L. 88-379 support.

EMPLOYMENT STATUS	Category of School Year Graduate by Degree Obtained: Bachelor's Degree	Master's Degree	Doctoral Degree	Total
1. No. employed in water related positions in:	1	1		2
Federal Agencies				
State & Local Agencies				
University or College				
Other - Including private enterprise		1		1
2. No. graduates returning to school for advanced degree	1			1
3. No. going into military service				
4. No. unemployed or working in other fields				
5. No. status unknown				
6. Totals	1	1		2

C. Type of employment of those school year graduates who received P.L. 88-379 support and who are known to have gone into water-related positions.

Number of Graduates Engaged in Water-Related Work in:	Bachelor's Degree	Master's Degree	Doctoral Degree	Total
1A. Federal Agencies:				
a. Primarily Research				
b. Primarily Planning				
c. Primarily Development				
d. Primarily Operations				
e. Primarily Management				
f. Other or not known				
1B. State & Local Agencies:				
a. Primarily Research				
b. Primarily Planning				
c. Primarily Development				
d. Primarily Operations				
e. Primarily Management				
f. Other or not known				
1C. University of College				
a. Primarily Teaching				
b. Primarily Research				
c. Primarily Research & Teaching				
d. Other or not known				
1D. Other - Including Private Enterprise				
a. Primarily Research				
b. Primarily Planning				
c. Primarily Development				
d. Primarily Operations				
e. Primarily Management		1		1
f. Other or not known				
Totals		1		1

Selected Summary of above data - from the "Total" column:

Research (1Aa, 1Ba, 1Cb, 1Cc & 1Da) -------------------	
Planning (1Ab, 1Bb & 1Dd) ----------------------------	
Development (1Ac, 1Bc & 1Dc) -------------------------	
Operations (1Ad, 1Bd & 1Dd) --------------------------	
Management (1Ae, 1Be, & 1De) -------------------------	1