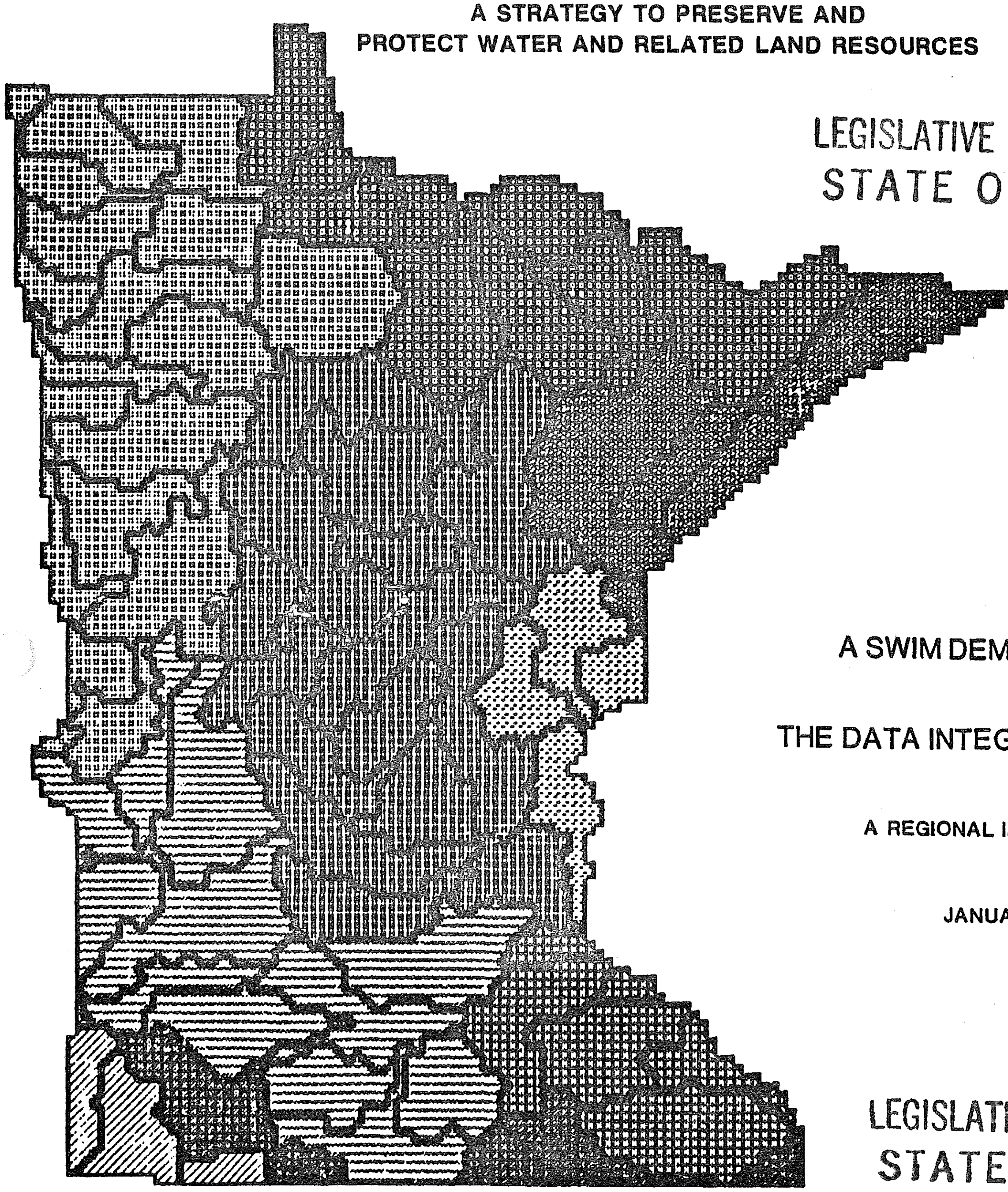
Toward Efficient Allocation and Management:

A STRATEGY TO PRESERVE AND PROTECT WATER AND RELATED LAND RESOURCES



A SWIM DEMONSTRATION OF

THE DATA INTEGRATION PROCESS:

A REGIONAL IRRIGATION STUDY

JANUARY 1980

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A REPORT OF THE MINNESOTA WATER PLANNING BOARD

TO

THE LEGISLATIVE COMMISSION ON MINNESOTA RESOURCES

AND

GOVERNOR ALBERT H. QUIE

ACKNOWLEDGEMENTS

"A Regional Irrigation Study" represents the efforts of individuals who were members of the Data Work Group. The development and extensive review of this report was also facilitated by the cooperation of representatives from many other agencies including the Departments of Agriculture, Natural Resources and Health; the Energy, Pollution Control, and State Planning Agencies; the Minnesota Geological Survey and the 6E Regional Development Commission.

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The maps were produced by the State Planning Agency's Land Management Information Center using their "Minnesota Land Management Information System" land use data files and integrating the water information supplied by the agencies mentioned above.

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SYSTEM FOR WATER INFORMATION MANAGEMENT PILOT STUDY

INTRODUCTION

The Legislative Commission on Minnesota Resources (LCMR), in its direction to complete a statewide Water and Related Land Resources Plan, requested the development of a water information system. Several efforts to organize such a system had occurred prior to 1977. The creation of the Water Planning Board in 1977 with its charge to complete a Framework State Water Plan by June 1979, resulted in significant progress on a water management information system. The Energy Agency was assigned responsibility for developing the system in consultation with a special inter-agency Data Work Group. The Data Work Group, along with a systems analyst from the Energy Agency, met regularly to discuss technical aspects and cordination needs of the system including entry of data, standardization of data and other issues central to the successful operation of such a system. Two facts became apparent during the course of their work. One was that the original concept of a large centralized data base tends to be infeasible for three reasons:

1) Loss of control in design and operation by data sources (it would make it extremely difficult for water management agencies to use their data in day-to-day operations if an inflexible format existed).

2) Technical problems (the University of Minnesota computer which will house most agency data bases is not designed to permit several users to have simultaneous access to a single data base).

3) Use of multiple computers (current individual systems operating or under development are utilizing several separate types of hardware at three different locations - the University of Minnesota, the State Information Systems Division, several federal systems).

A better approach than centralization of actual data was felt to be an integrated system based on common linkages and common geographic identifiers which would permit the accessing of several sources of data when necessary.

The second fact to become apparent was that given the time and money constraints there would not be enough statewide information to demonstrate the utility of such an overall information system.

The Data Work Group felt it was very important to demonstrate, before the Draft Water Plan was completed in July 1979, the kinds of things that the System for Water Information Management (SWIM) could do now in a limited area and could be expected to do in the future on a statewide basis. For this reason, a pilot study was proposed for one particular geographic area in the state and for one water issue. It should be emphasized that this pilot study is only one example of SWIM's capability to bring together water related data from several line agencies to arrive at a more comprehensive answer to a specific question. The Data Work Group could have chosen any number of projects to demonstrate the advantages of the SWIM system. For example, it could have determined a water balance analysis within a watershed(s). Some of the types of information one could use in this analysis would be: (1) DNR's water appropriation's permits, (2) land use types found in the MLMIS data bank to estimate runoff potenital, and

(3) the MPCA's point source discharge data. Another example of a pilot study might have been a regional identification of potential areas of groundwater contamination. Data useful in making that kind of determination might be: (1) MGS' subsurface data to identify soil types and permeability rates, (2) MDH's well log data to identify the number and extent of contaminated wells already found in the study area, (3) DNR's well log data for pumping rates, etc., (4) MPCA's groundwater and surface water data as well as location their permitted point source and non-point source discharges, and finally (5) searching the MLMIS data bank to isolate areas of karst topography or other geologic areas with a high potential for surface contamination.

Methodology

The pilot study on irrigation or the hypothetical projects cited above are only examples of how SWIM might join together several unique data bases with relevent information to arrive at an end product. Each individual data bank has limited applications and planning functions outside of its parent agency. However, by joining data systems together in a logical formula, our knowledge and understanding of the State's water resources can be greatly expanded.

The pilot study has two significant aspects. One is the product, the set of maps and discussion that center around an actual problem of interest both to state agencies and to the people living in a particular geographic area. The second is the process of developing that product, an aspect significant to the internal design of the system. Only by trying to fit together bits and pieces of information from diverse sources would the system developers become aware of the problems and alternative solutions for the successful operation of an integrated system. Data questions such as incompleteness, poor geographic references, poor quality, and use of data originally gathered for a different purpose would have to be addressed.

The Data Work Group chose Region 6E as a pilot area. That regional development commission (RDC) had shown considerable interest in working with water issues and had been cooperating with and providing assistance to the Minnesota Geological Survey since 1977 on a water well inventory in the area. Because of that inventory all the available subsurface geologic information was in a computerized data base for McLeod, Meeker, Kandiyohi, and Renville Counties.

The RDC director suggested three water-related topics that would be of particular interest to Region 6E, (1) potential for groundwater pollution, (2) potential water supply problems, and (3) irrigation. The Data Work Group decided on the topic of irrigation because it was of statewide (to the Legislature and several state agencies) and local concern. The drought of the mid-1970's had spurred the use of irrigation in Minnesota and several agencies were involved in evaluation of its implications. A statewide inventory of irrigation locations was being developed by the Department of Agriculture. The Department of Natural Resources was developing aquifer and water-use data bases to better evaluate irrigation impact and the allocation of water appropriation permitting. In addition, it was felt that better and more diverse data sources about irrigation could be used to demonstrate the actual and potential capabilities of

SWIM. Meeker and Kandiyohi counties became the focus because very little irrigation was occurring in the other counties in 6E.

An Irrigation Subgroup of the Data Work Group was formed which reflected the interdisciplinary and interagency effort and cooperation necessary to make an integrated system work. Some provided actual data, some provided helpful comments on how to use the data and others did the systems work which brought the diverse data sources together. The agencies and divisions involved were:

Mn. Department of Agriculture (MDA) - Planning Division

Mn. Department of Natural Resources (DNR) - Division of Waters

Minnesota Geological Survey (MGS)

Minnesota Energy Agency (MEA)

Minnesota Department of Health (MDH)

Minnesota State Planning Agency (SPA) - Environmental Planning; Land Management Information Center

The Irrigation Subgroup identified a number of irrigation related interests which concern individuals, public agencies, and local planning units. The DNR has interest in water allocation and distribution to help estimate the demand of ground water for irrigation purposes. This could help evaluate future potential conflicts in water use between irrigators and other large volume water users. The evaluation of water demand using permit and hydrologic data could help to define agricultural needs when water supplies are inadequate or user conflicts arise. Identification of irrigators who should report pumpage and are not doing so is also of interest to the DNR so that more accurate estimates of total water demands for irrigation can be determined. Additional information in making regional water demand estimates can come from knowledge of crop irrigation needs. Farmers using irrigation can benefit from this information to help plan irrigation timing and quantity for specific crops.

The MGS utilizes well log data to determine the subsurface geology of the state and in preparing geologic and hydrogeologic maps. These types of information are of value to anyone involved in water management programs and planning such as: local governments, the DNR and MDA, Soil and Water Conservation Districts, the Soil Conservation Service, county extension agents, and individual farmers.

The correct location of irrigation systems is needed to help in the planning of other land use activities which may conflict within these areas. For example, State Planning's Power Plant Siting program and the power companies can use this information to aid in siting electrical transmission lines so they do not interfere unduly with irrigation equipment.

The Minnesota Department of Health and the Pollution Control Agency need information on the location of irrigation activities to aid in delineating areas where groundwater or surface water quality may be impaired by infiltration or runoff of irrigation waters containing agricultural chemicals.

Identification of land most suited to irrigation is of benefit to those involved in individual decisions of whether or not to irrigate. This information is also useful to those involved with agricultural and land use planning, economic projections, and water management decisions.

The assessment of the economic impact of irrigation is an aid, especially to the MDA, in determining the state's present and future agricultural productivity. Evaluation could be made of the future economic impacts that irrigation might afford contract crop farmers.

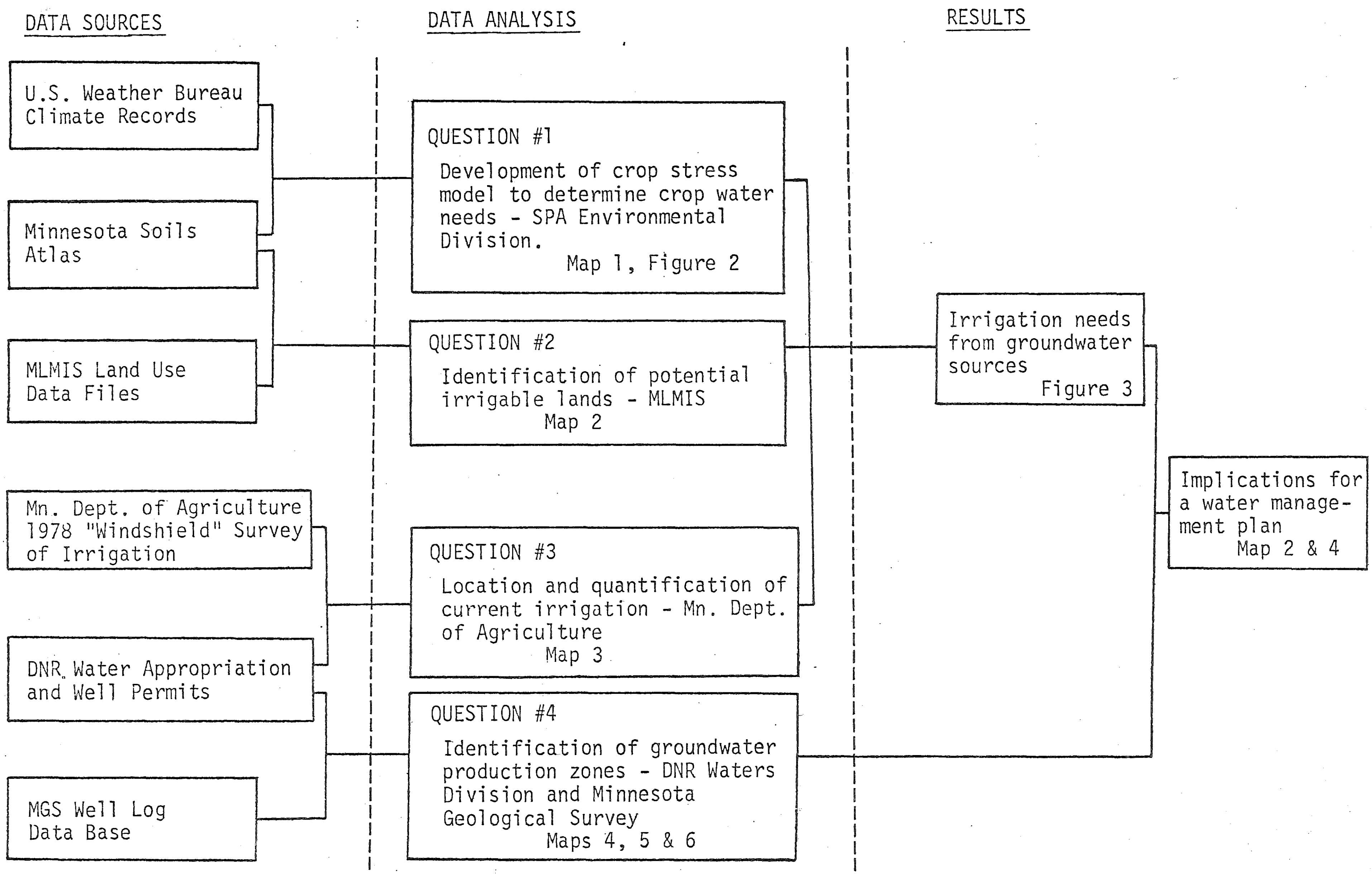
A number of questions emerged from Irrigation Subgroup discussion of these interests in irrigation and related data. The answering of these questions demonstrates the multi-purpose benefit of S IM as a tool (1) for agencies and local units both in their planning and regulatory functions and (2) for both descriptive and predictive investigations in resource use.

The questions identified were:

1. How much irrigation is required to supplement precipitation?
2. Where are the potential irrigable lands?
3. How much acreage is currently being irrigated, where is it, and what crops are being grown on these lands?
4. Where are water supplies available for irrigation purposes?
5. Where are potential areas where the quality or quantity of surface and/or groundwater supplies may be affected by irrigation pumpage?
6. What is the economic significance of irrigation?

The answers to questions one through four are found in this report. Due to limitations of time, expense, and existing data availability questions five and six were not addressed. The data compilation and analysis which was completed does provide information useful to policy makers who have to plan and regulate the use of groundwater resources. Figure One identifies the data input participants in this pilot study and the analysis procedure leading to an estimate of groundwater use in Kandiyohi and Meeker counties for irrigation purposes.

Figure 1: SYSTEM FOR WATER INFORMATION MANAGEMENT PILOT STUDY



STUDY ANALYSIS

Question 1: Irrigation Needed to Supplement Precipitation

To determine the additional water needs of crops beyond normal precipitation, a crop stress model was developed by the Environmental Planning Division of the State Planning Agency.

This crop stress model examines the parameters affecting drought (rainfall, crop use, soil type) to determine when during the growing season, crops on given soil types are most apt to suffer water shortages, both during normal and dry years. The model also estimates how much additional water the crops on these drought-prone soils would require beyond normal precipitation.

The two variables used to develop the crop stress model were soils data and variations in precipitation and temperature of Meeker and Kandiyohi counties. Map 1 shows the soils grouped according to the first day of computed drought using dry year precipitation. The sandy textured soils, situated in the north and northwest part of the region, are subject to drought beginning from early to mid-July. Corn grown on these soils will suffer severely since tasseling coincides with the drought period. The heavier soils, located throughout the major portions of the region, will experience the beginnings of computed drought between late August and mid-September. Corn yields produced on these soils will be substantially higher than those grown on sand since the drought period does not occur during the critical reproductive stages of plant growth.

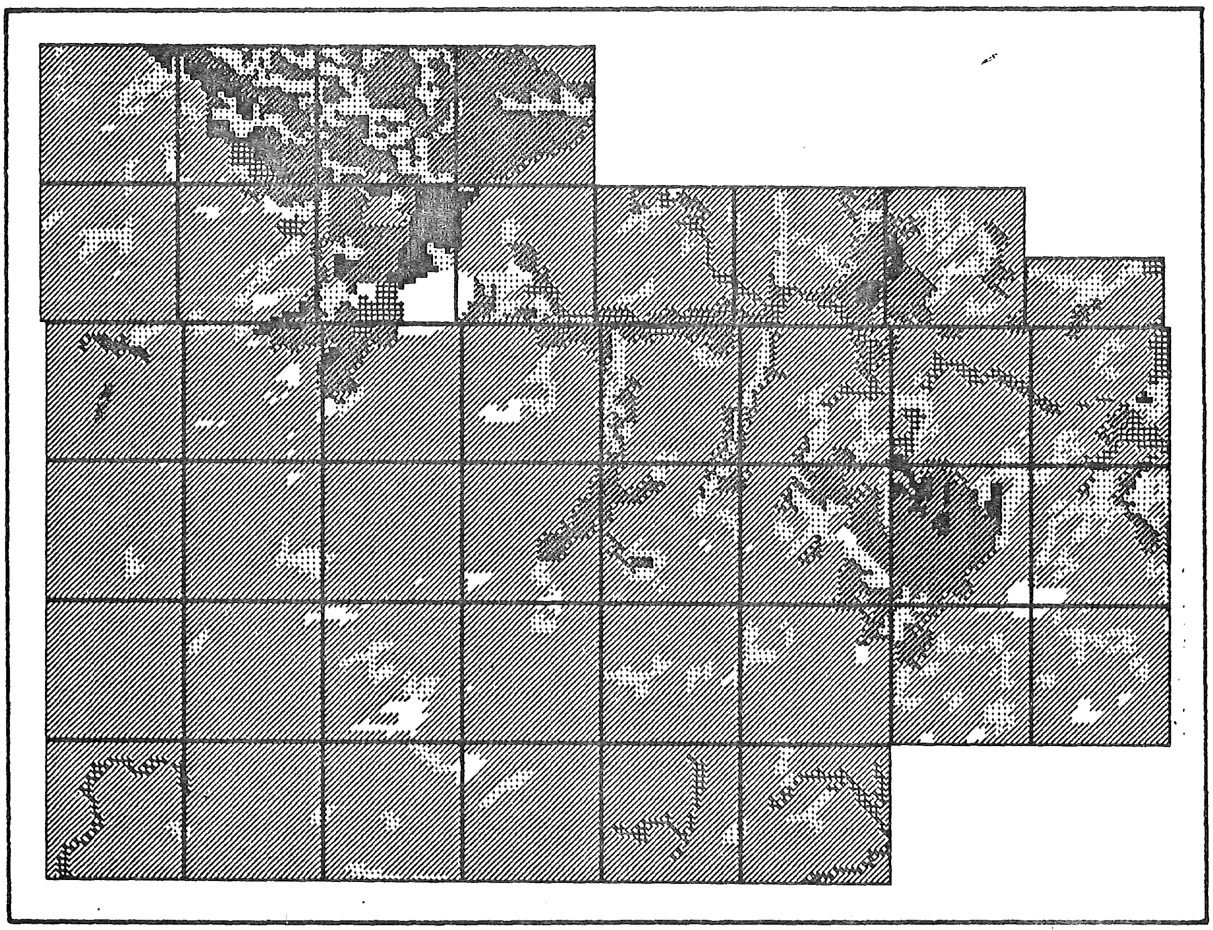
To determine the first day of drought the crop stress model calculates the daily soil moisture balance for each soil group having a different

MAP 1

CALCULATED DROUGHT IN REGION 6-E

Drought Occurrence Determined for
a Growing Season May 1-Sept. 30

Evapotranspiration Calculated Using Thornthwaite's Model
and 80% of Average Precipitation Based on 19-28 Years of Records
for 9 Local Weather Stations in the Region



Level	Symbol	Description
		Early to Mid-July HIGHEST CROP STRESS
		Mid to Late July HIGH CROP STRESS
		Early to Late August AVERAGE CROP STRESS
		Late August to Mid-September LOW CROP STRESS
		Marsh and Peats NO CROPS
		Water NO CROPS

moisture holding capacity in the rooting zone. The daily soil moisture balance is calculated by adding the soil moisture level to the daily precipitation and subtracting the evapotranspiration from this total. A simplified example of the water balance tabulation for soils of 4" and 6" moisture-holding capacities is shown in Figure Two. It should be noted that when the soil moisture level drops below one inch, the plant cannot take advantage of the moisture and drought begins. This example uses climatic data from the Bird Island area for a dry year. The 75% soil moisture recharge level of the rooting zone is a common condition where pre-planting precipitation does not recharge the soil profile to capacity. The model is readily adaptable to different soil, climate, and crop situations.

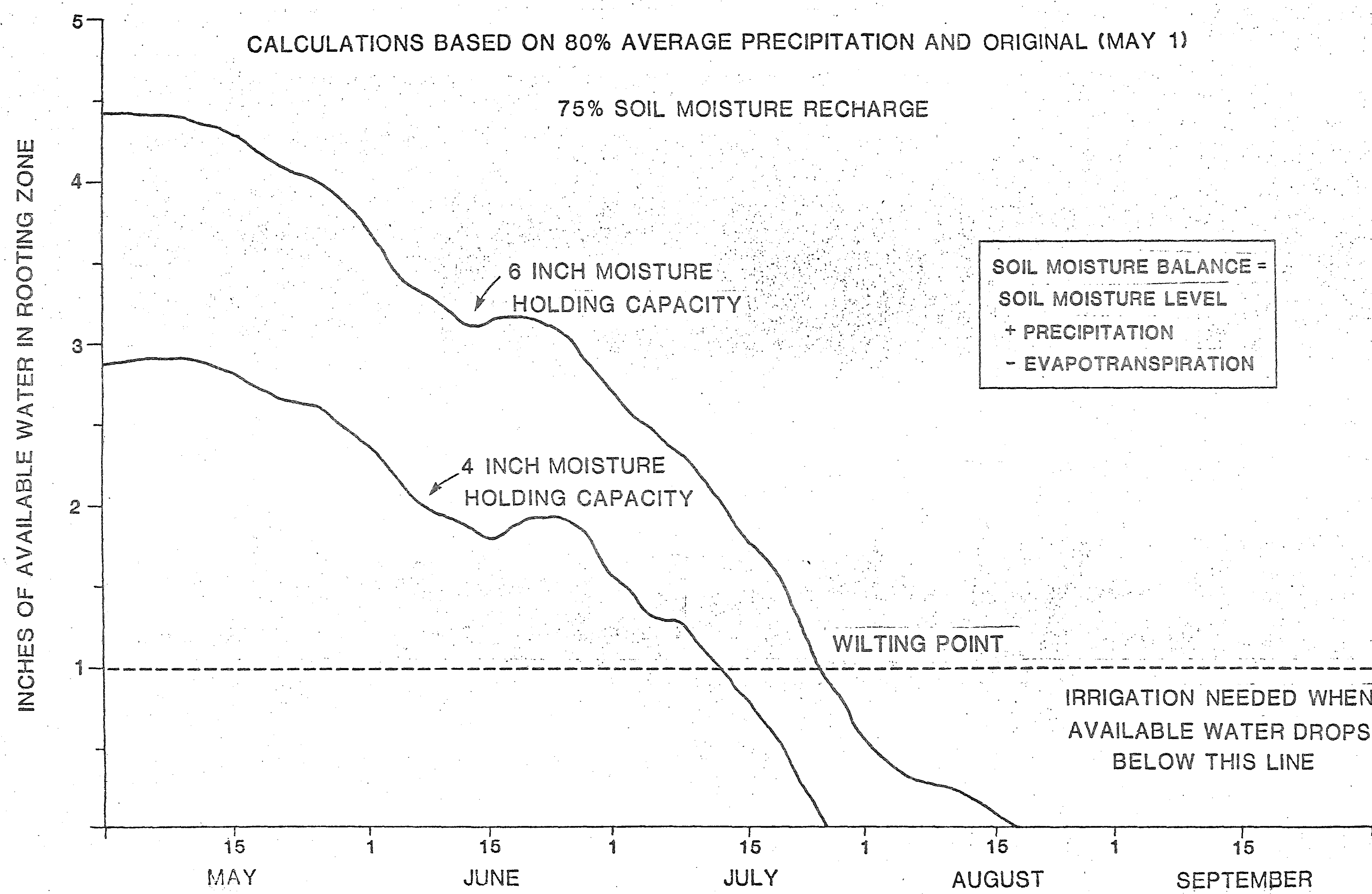
Irrigation water requirements were determined for those soil types which experienced calculated drought. The water demand beyond seasonal rainfall was computed by subtracting potential evapotranspiration (the water plants use if readily available) from expected precipitation. To determine the actual number of inches which must be pumped through irrigation to make up this difference factors of sprinkler and natural precipitation efficiencies were added to the crop stress model. This provides an estimate of irrigation pumpage required on any soil type in a complete range of climatic variations. Map 2 includes irrigation pumpage requirements needs for soils of 4" - 6" moisture holding capacity in a dry-year situation.

Question 2: <u>Identification of Potential Irrigable Lands</u>

Potential irrigable areas were identified in the study area using data from the Minnesota Soil Atlas and land use data files from the MLMIS.

FIGURE 2

WATER BUDGET OF SOILS HAVING 4 AND 6 INCH MOISTURE HOLDING CAPACITY AT BIRD ISLAND



The crop stress model has identified the soils having 4" and 6" moisture-holding capacities as being drought-prone. Using this knowledge and excluding areas with agricultural land use restrictions (areas of water and marsh) the potential irrigable areas were determined. Map 2 is an example using drought-prone soils in a dry climate situation. These drought-prone soils are sands and sandy loams and respond most favorably to irrigation practices. The loams and clay loams not included on the irrigation potential map are subject to such problems as field puddling when irrigated.

Question 3: Location and Quantification of Current Irrigation

The question of how much acreage is being irrigated and what crops are being grown on these lands was answered using two surveys completed by the Minnesota Department of Agriculture. One was a 1978 field, or "windshield", survey of irrigated acreage and the other was a search of Department of Natural Resources water appropriation permits. The two surveys were conducted to (1) verify the DNR permits and (2) obtain a more accurate estimate of irrigated acreage.

From the "windshield" survey and permit data entered in MLMIS, 307 forty-acre parcels (12,280 acres) were identified and verified as being actively irrigated during 1977 and 1978 in Kandiyohi and Meeker counties. The location of these forty-acre parcels is shown on Map 3. The forty-acre parcels being irrigated in 1978 are shown in black plus an additional 142 forty-acre parcels (5,680 acres) which had permits outstanding but had not been verified by either survey or pumpage reports. These irrigation locations are also found on Maps 4, 5, and 6 in the following section on groundwater production zones.

Question 4: Identification of Ground Water Production Zones

The Minnesota Department of Natural Resources Division of Waters and the Minnesota Geological Survey provided the data to determine potential groundwater yield to wells in Kandiyohi and Meeker counties.

MGS maintains a well log data base which consists of information supplied by water-well contractors. This is an important source of the MGS' knowledge of geologic strata in the state. The DNR requires a permit for groundwater appropriation and from these permit files information on location and pumpage quantity can be obtained. Using the MGS well log data base and the DNR permit files, the water bearing formations utilized by wells in Kandiyohi and Meeker counties were divided into production zones based upon the elevations of the water producing sands. However, these production zones cannot be defined as aquifers because two or more of them may be hydrologically connected in some areas. An extensive ground water study would have to be performed in order to delineate specific aquifers.

The production zones and their elevations are shown on Maps 4, 5, and 6. These maps also contain black symbols which represent the 40 acre parcels being irrigated as defined in Question 3.

The potential yield for each zone was calculated by multiplying available hydraulic head times specific capacity for wells where the data exist. The yield values were then divided further into high, medium, and low ranges based on arbitrary cutoffs of 250 and 500 gpm.

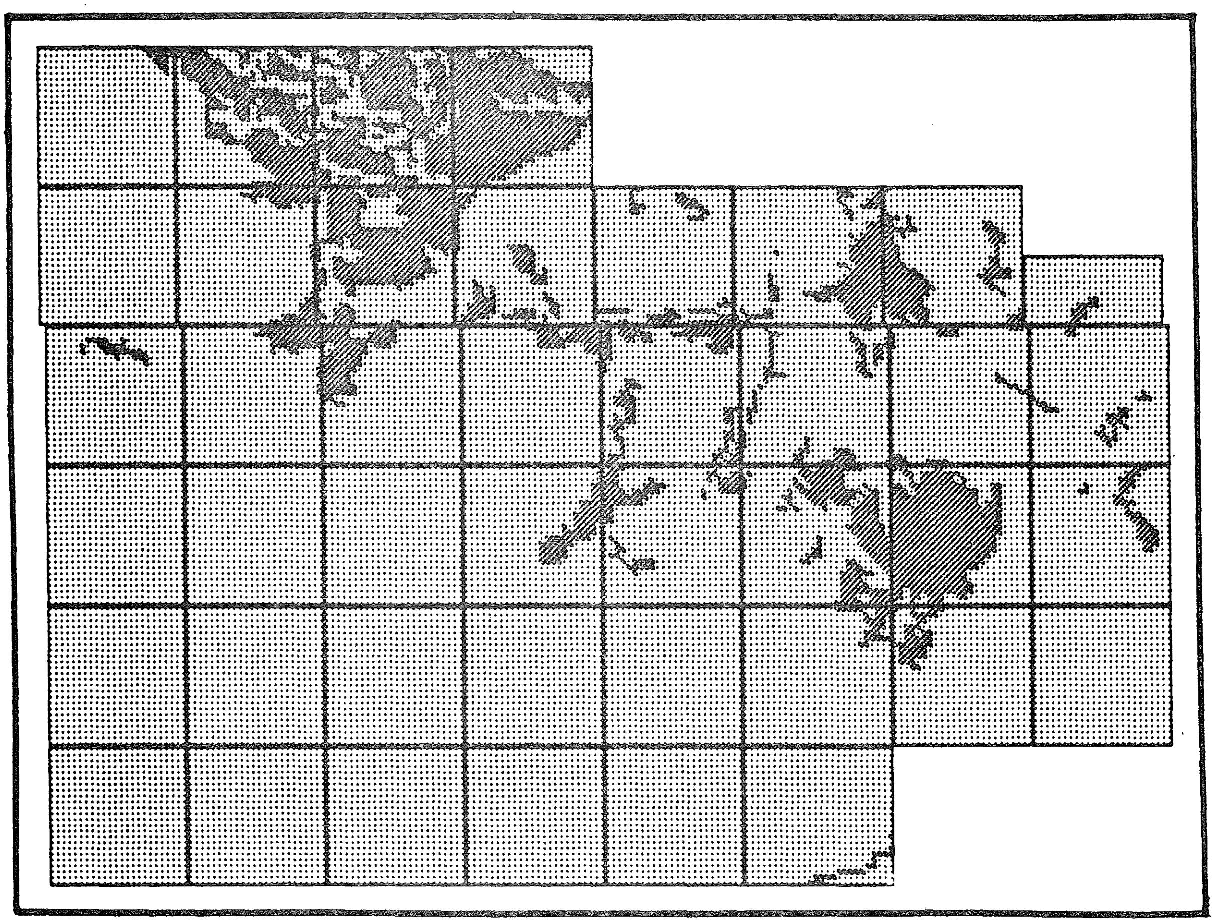
The areal extent of each production zone was defined in the following manner. If a well log contained a sand layer in the production zone, a

MAP 2

AREAS WHERE SOILS HAVE POTENTIAL FOR IRRIGATION AND THEIR WATER REQUIREMENTS

SOILS WITH A IRRIGATION POTENTIAL DETERMINED FOR
A GROWING SEASON MAY 1 - SEPT. 30

POTENTIAL EVAPOTRANSPIRATION CALCULATED USING THORNTHWAITE'S MODEL. ASSUMED 80% OF AVERAGE PRECIPITATION. PRECIPITATION AVERAGES BASED ON 19-28 YEARS OF RECORDS FOR NINE LOCAL WEATHER STATIONS IN REGION 6-E. (EVAPORATION LOSS OF BOTH SPRINKLER WATER AND PRECIPITATION IS INCLUDED).



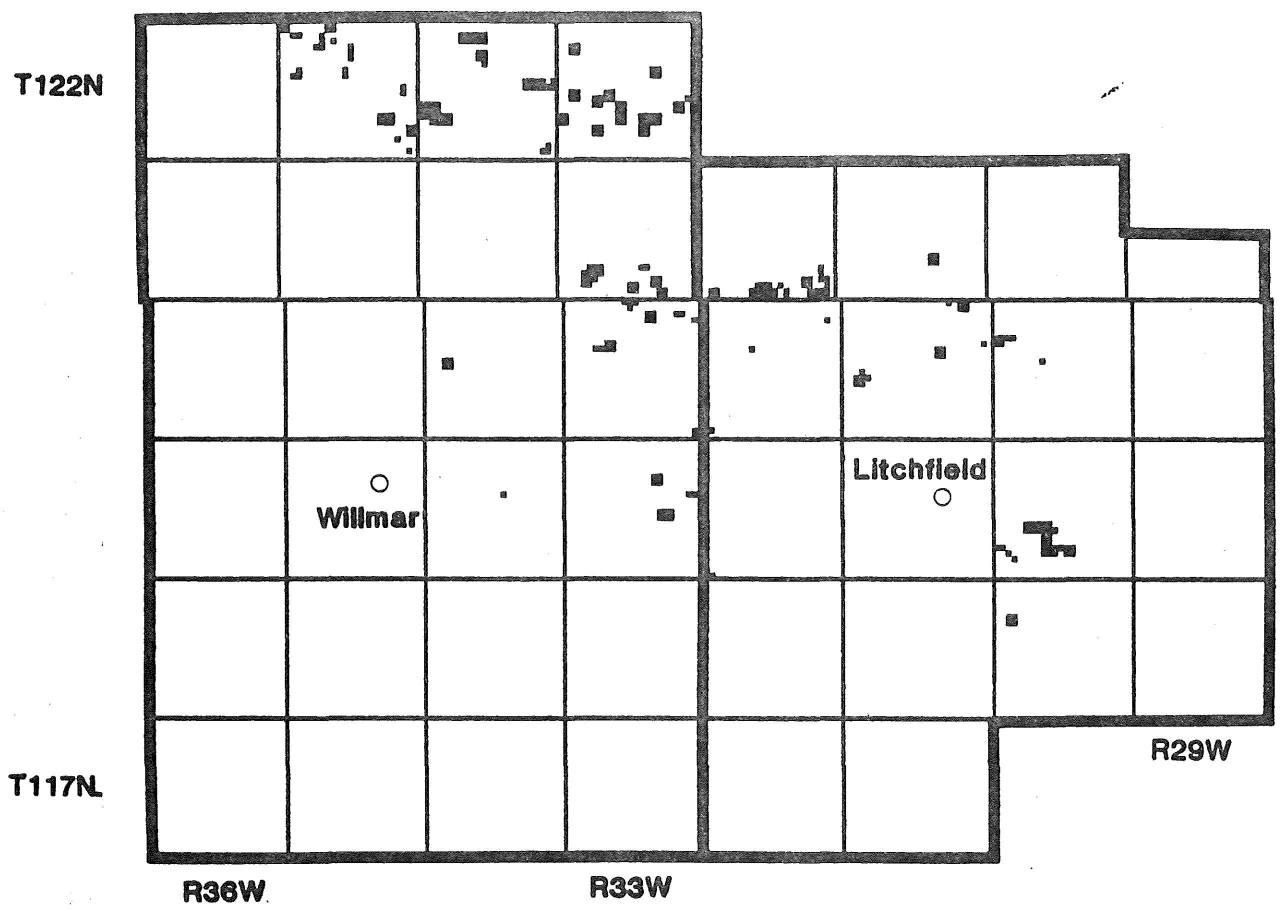
Level	Symbol	Description
1		SOILS MOST SUITABLE FOR IRRIGATION REQUIRING 11-18" OF IRRIGATION
2		OTHER SOILS LESS SUITABLE FOR IRRIGATION, PEATS, MARSH, AND WATER

MAP 3

LOCATION OF CURRENT IRRIGATION

IRRIGATED ACREAGE IDENTIFIED AND VERIFIED AS BEING ACTIVELY IRRIGATED

DATA FROM 1978 "WINDSHIELD" SURVEY AND 1977 PUMPAGE RECORDS



LEVEL	SYMBOL	DESCRIPTION
1	■	Irrigation Site
2	□	No Irrigation

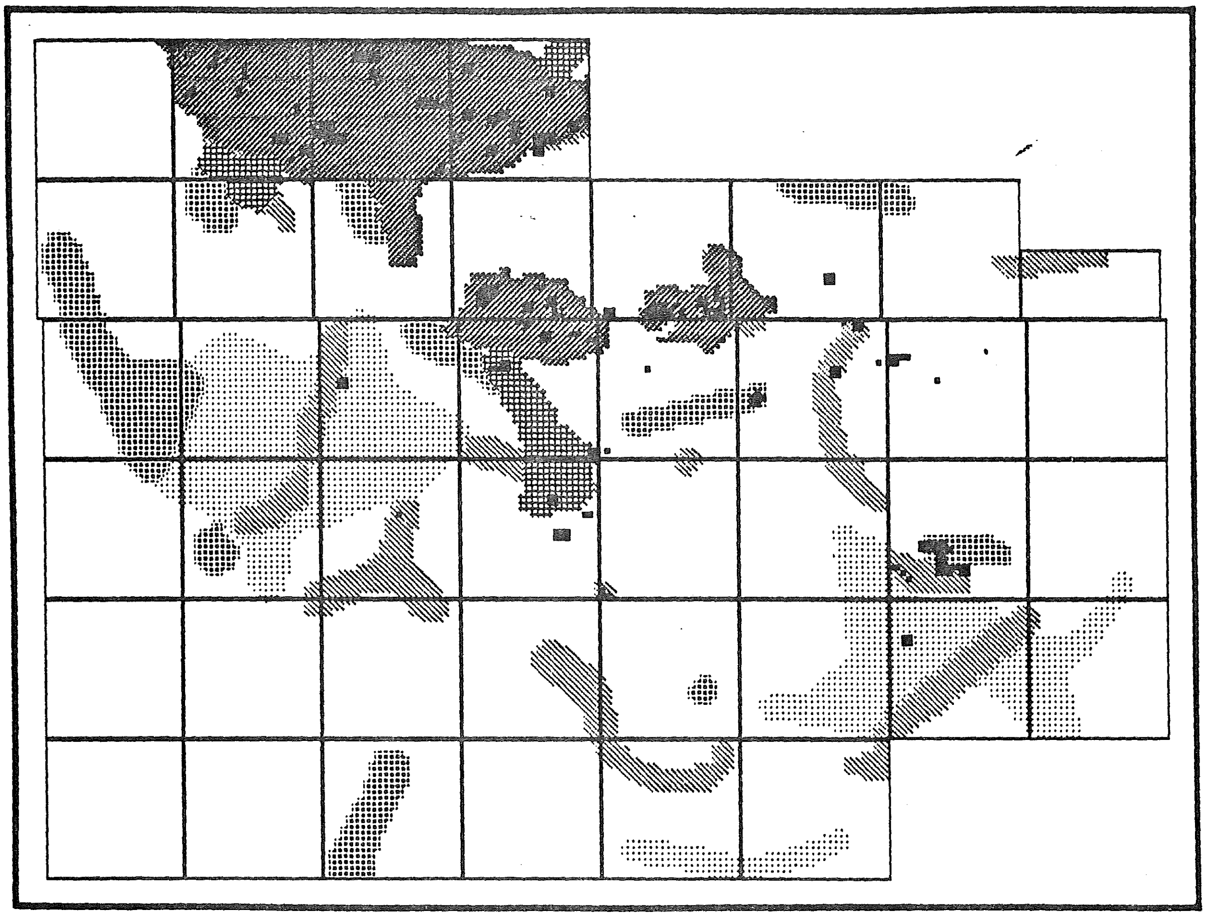
MAP 4

HIGH POTENTIAL YIELD AREAS

MAXIMUM PUMPAGE RATE OF MORE THAN 500 GALLONS/MINUTE

CLASSIFIED ACCORDING TO THE SUBSURFACE ZONE IN WHICH THIS PUMPAGE RATE CAN BE MAINTAINED

THE PRODUCTION ZONES ARE NOT DEFINED AS AQUIFERS SINCE ONE OR MORE ZONES IN A GIVEN AREA MAY BE HYDRAULICALLY CONNECTED.



LEVEL	SYMBOL	DESCRIPTION
1		IRRIGATION ACTIVITIES
2		SURFICIAL OUTWASH AQUIFER
3		UPPER SHALLOW ZONE (1140-1220 FEET ABOVE MEAN SEA LEVEL)
4		LOWER SHALLOW ZONE (1030-1140 FEET ABOVE MEAN SEA LEVEL)
5		INTERMEDIATE ZONE (970-1030 FEET ABOVE MEAN SEA LEVEL)
6		DEEP ZONE (UP TO 970 FEET ABOVE MEAN SEA LEVEL)
7		NO KNOWN POTENTIAL AT THIS PUMPAGE RATE

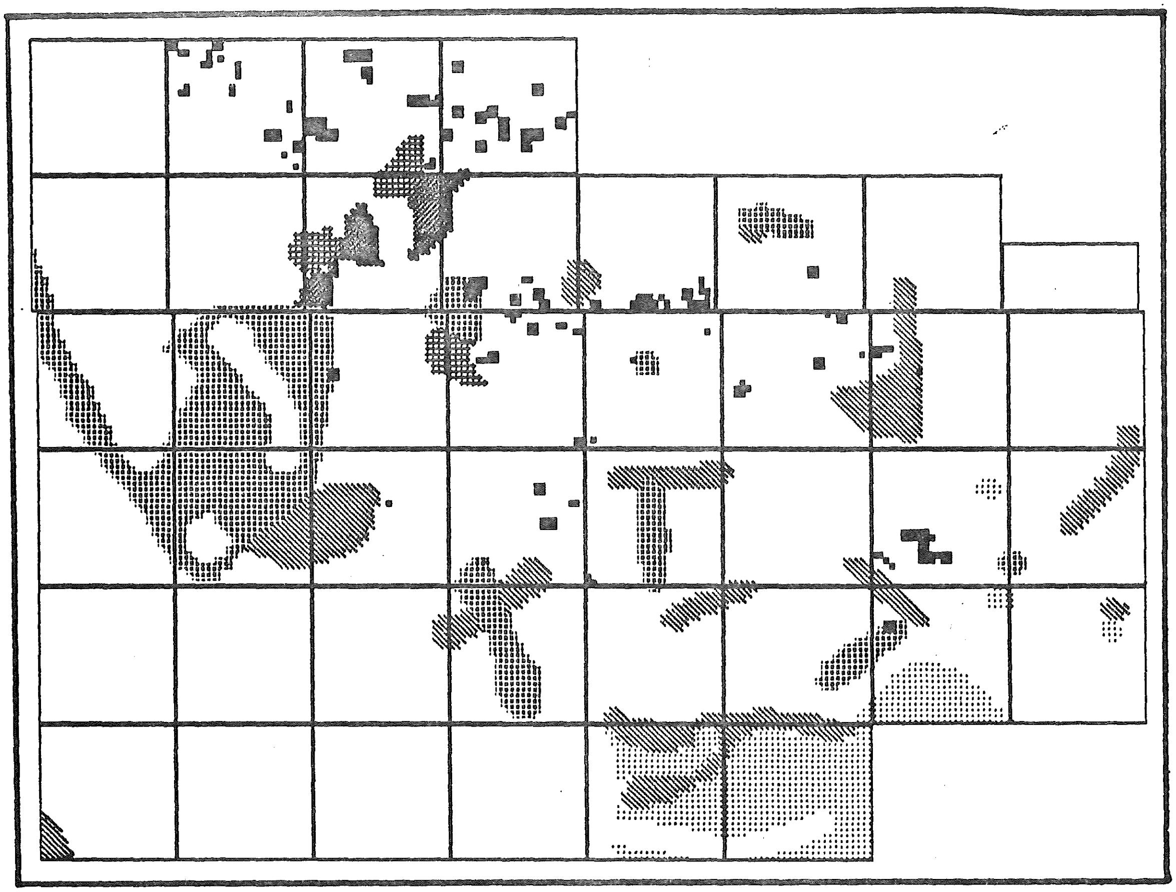
MAP 5

MEDIUM POTENTIAL YIELD AREAS

MAXIMUM PUMPAGE RATE OF 250 TO 500 GALLONS/MINUTE

CLASSIFIED ACCORDING TO THE SUBSURFACE ZONE
IN WHICH THIS PUMPAGE RATE CAN BE MAINTAINED

THE PRODUCTION ZONES ARE NOT DEFINED AS AQUIFERS SINCE ONE OR MORE ZONES IN A GIVEN AREA MAY BE HYDRAULICALLY CONNECTED.



LEVEL	SYMBOL	DESCRIPTION
1		IRRIGATION ACTIVITIES
2		SURFICIAL OUTWASH AQUIFER
3		UPPER SHALLOW ZONE (1140-1220 FEET ABOVE MEAN SEA LEVEL)
4		LOWER SHALLOW ZONE (1030-1140 FEET ABOVE MEAN SEA LEVEL)
5		INTERMEDIATE ZONE (970-1030 FEET ABOVE MEAN SEA LEVEL)
6		DEEP ZONE (UP TO 970 FEET ABOVE MEAN SEA LEVEL)
7		NO KNOWN POTENTIAL AT THIS PUMPAGE RATE

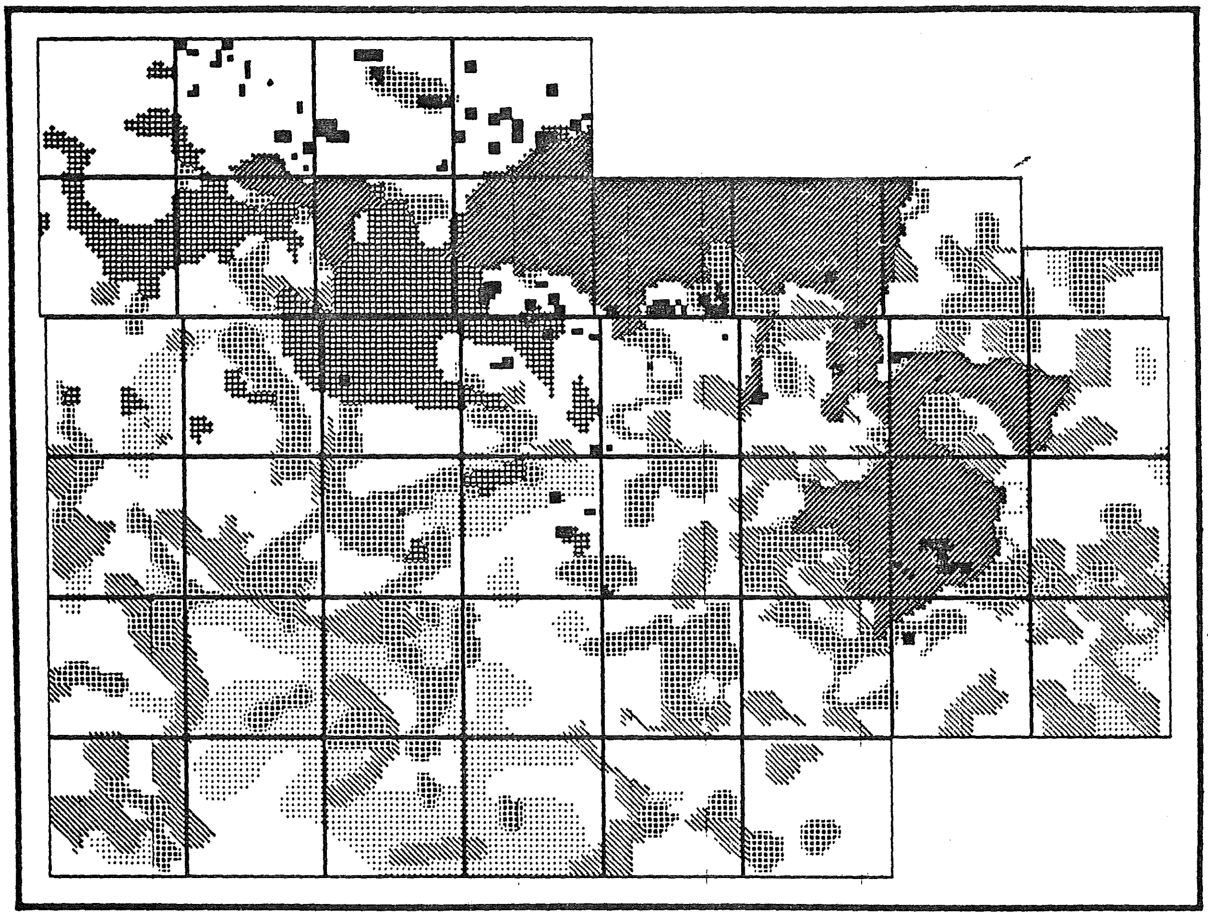
MAP 6

LOW POTENTIAL YIELD AREAS

MAXIMUM PUMPAGE RATE OF 0 TO 250 GALLONS/MINUTE

CLASSIFIED ACCORDING TO THE SUBSURFACE ZONE
IN WHICH THIS PUMPAGE RATE CAN BE MAINTAINED

THE PRODUCTION ZONES ARE NOT
DEFINED AS AQUIFERS SINCE ONE
OR MORE ZONES IN A GIVEN AREA
MAY BE HYDRAULICALLY CONNECTED.



LEVEL	SYMBOL	DESCRIPTION
1		IRRIGATION ACTIVITIES
2		SURFICIAL OUTWASH AQUIFER
3		UPPER SHALLOW ZONE (1140-1220 FEET ABOVE MEAN SEA LEVEL)
4		LOWER SHALLOW ZONE (1030-1140 FEET ABOVE MEAN SEA LEVEL)
5		INTERMEDIATE ZONE (970-1030 FEET ABOVE MEAN SEA LEVEL)
6		DEEP ZONE (UP TO 970 FEET ABOVE MEAN SEA LEVEL)
7		NO KNOWN POTENTIAL AT THIS PUMPAGE RATE

half-mile radius was drawn around the well location. Every quarter section touched by the circle was then included in tha production zone. The surficial production zones are under water-table conditions; all others are under artesian conditions.

POSSIBLE FUTURE ANALYSIS

Question 5 dealt with the location of areas where the quality and/or quantity of surface and/or ground water supplies may be affected by irrigation pumpage. It was felt that additional hydrologic and water chemistry data would have to be collected and analyzed before accurate answers could be developed to this question. This information would be helpful to the Pollution Control Agency, the Health Department, the DNR and local governments in developing regulations for irrigation.

Question 6 was to investigate the economic significance of irrigation. It was hoped that, along with the information developed under the preceding questions, additional work could be done using an economic input-output model developed at the University of Minnesota. The Planning Division of the Department of Agriculture was to look into this question but sufficient information to carry out the study was not available.

RESULTS

Irrigation Needs From Groundwater Sources

The question of irrigation required to supplement precipitation was taken one step further to estimate how much water is being used for irrigation in Kandiyohi and Meeker counties. An estimate was prepared by comparing the irrigated acreage figures for 1977 and 1978 derived from the permit and "windshield" surveys with the water needs estimates of the crop stress model and the delination of irrigable soils.

As mentioned under Question 3, 307 parcels (12,280 acres) were identified and verified, either by "windshield" survey or by pumpage records, as being actively irrigated in either or both 1977 and 1978 and a composite was generated of the two years. An additional 142 parcels (5,680 acres) had permits outstanding but had not been verified by either survey or pumpage reports. Thus, there are two sets of estimates: "low" (based on 12,280 acres) and "high" (based on 17,960 acres).

The crop stress model was used to calculate crop water and irrigation pumpage needs of soils with four different moisture holding capacities during an "average" precipitation year with 75% soil moisture recharge. The estimate can also be made for a "drier-than-average" year.

Locations of irrigated fields were crosstabulated with general soil types to get an approximate percentage of irrigated acres on soils of different moisture-holding capacities. Because the generalized soils information does not always reflect site-specific conditions, a considerable amount of irrigated acreage appears to occur on soils of 8" and 10" moisture-holding capacity. This situation is unlikely but for statistical reasons they are included in the estimate below:

Soil Type	Low Est. of # of Acres	Irrigation Required (inches)	# of Gallons (millions)/ Growing Season
4"	200	12.3	66.8
6"	8,480	9.6	2,210.4

8"	520	7.3	103.1
10"	3,080	5.5	460.0
Total Using Low Irrigated Acreage Estimate			2,840.3
Total Using High Irrigated Acreage Estimate			4,154.0

There are a number of other methods to estimate irrigation needs and two of them were employed using the same parameters as the crop stress model.

From the "rule-of-thumb" method used by the Irrigators Association of Minnesota, the following figures were derived:

Using Low Irrigated Acreage Estimate: 2,892.6 million gal/growing season
Using High Irrigated Acreage Estimate: 4,230.6 million/gal/growing season

For purposes of comparison, the potential amount of irrigation pumpage was also estimated using the DNR permitted amount of 12" for an average year. (This standard permitting amount was discontinued by DNR in 1978 in favor of using the S.C.S. Irrigation Guide.)

Using Low Irrigated Acreage Estimate: 4,003.3 million gal/growing season
Using High Irrigated Acreage Estimate: 5,855.0 million gal/growing season

Each of these methodologies offers some advantages and disadvantages in estimating state or regional water use. The crop stress model and U.S. Soil Conservation Service Irrigation Guide methods both utilize soil moisture-holding capacity data. The SCS method requires detailed soils survey data which does not exist for the whole state; this lack of data prevents statewide application. The SCS method also utilized very broad climatic zones in its estimation of plant water use. The crop stress model is very flexible in use of climatic data and allows for use of much more localized climate data than does the SCS method. Using the more generalized Minnesota Soil Atlas data with the crop stress model makes it less site-specific, but the more detailed SCS soil survey data could be used where available.

The "rule-of-thumb" method used by the Irrigators Association of Minnesota is a site-specific formula to be used by the individual irrigator. It requires measurements of soil moisture depth and precipitation, thus making it less applicable to modeling techniques for statewide purposes. For this pilot study, only one soil type and one soil moisture class was used for all sites.

The DNR practice of allowing 12" per year was used until 1978 because no quantative, site specific method for determining irrigation pumpage was available until the S.C.S. Irrigation Guide came into use.

CONCLUSION

This pilot study helps to illustrate the feasibility of developing a water management information system. The techniques needed to develop data interaction within the system were explored and various components of the water cycle were linked by the systematic use of information to answer questions.

The importance of integrating data from diverse sources was demonstrated in the pilot study. The two surveys of irrigation, MGS and DNR yields, and the MLMIS data were all developed separately and then linked through the use of common geographic identifiers. The integration of this data made possible the estimation of irrigation pumpage in the study area by combining irrigation location data with data from the crop stress model. A method was developed for applying current techniques and data to the geographic (spatial) aspects of water demand and supply for irrigation. In comparison to methods used by individuals to determine their irrigation needs, the pilot study produced information useful for calculations at a regional scale. Decisions can thus be better made at a collective versus individual level for planning the use of water resources.

One of the problems encountered in this study was in dealing with the differences in the degree of geo-referencing reliability which exist between various data collection programs. It was found that each agency has its own standards established to meet a specifically-designed need. These differences are the result of defining different goals. For example, one program requires locational accuracy to within 10 meters, while another program collecting similar data can meet its objectives with very little reliability on the locational accuracy.

Because location is so fundamental to any agency's ability to identify where environmental problems exist and what may be their areal extent, some basic accuracy standard should be agreed upon for all information stored or accessible through SWIM. This standardization process will prove beneficial to all users in both their short and long term use of the data. It will always be the user's responsibility to determine whether or not the quality level of the primary data is adequate to meet their needs, but the user has the option of contacting either the SWIM service bureau or the primary data collector when the user requires further clarification of available data.

Technical studies of the nature used here can contribute to the development of policy and management. The evaluation of permit requests for ground water use can be made more accurately when aquifers can be better defined, their maximum yields more readily evaluated, and their current use determined. In addition, estimated future demands can be compared with accurate information of groundwater supplies to help planners make more precise long range water resource development decisions.

APPENDIX

I. DETERMINATION OF CROP WATER NEEDS USING CROP STRESS MODEL

The procedure used to determine drought conditions was the computation of the daily balance of available soil moisture for the growing season (May 1 through September 30) for each soil type in the study region. A drought situation was determined whenever the moisture balance for a given soil reached zero. Each day the supply of water was below the level of availability to the plant was called a "drought day".[1] The number of drought days were then totalled for each soil type. However, the timing of the drought during the growing season is more important than the absolute number of drought days for a given soil. For example, drought in July will reduce corn yields more significantly than drought in September. Yield reductions of up to 50% can be expected if three to four successive drought days occur during the silking and tasseling stages of corn. Several days of drought in mid-September will have limited affect on corn yields since ear maturation has usually been reached by this time. Therefore, the timing and duration of drought is significant and the dates were recorded whenever drought occurred.

Modeling drought requires quantitative data on three variables to be used in the soil moisture computations. These are: (1) daily water loss through evaporation and plant transpiration (evapotranspiration) (2) daily precipitation and (3) available water holding-capacity of

[1]G.R. Blake, et al. Agricultural Drought and Moisture Excesses in Minnesota, Agricultural Experiment Station, University of Minnesota, Technical Bulletin 235.

the soil. Each of these variables is considered separately in the discussion below.

Variables Used in Analysis

Evapotranspiration is the loss of water from a soil by evaporation and plant transpiration. Evapotranspiration (ET) represents the water comsumed in producing a crop. Field measurements of ET are difficult to make and are outside the scope of this investigation. However, formulas are available which can be used to determine ET if the necessary climatic data can be obtained. Thornthwaite's procedure was chosen since it allows for differences between potential and actual consumptive water use.

A brief discussion of Thornthwaite's method[2] (the one used in this study) is provided below.

Mean daily temperature and precipitation are the principal measures needed to compute potential and actual ET using Thornthwaite's system. These variables, coupled with conversion tables relating sunlight to latitude (provided in Thornthwaite's documentation), permit the necessary calculations.

Consideration of potential and actual evapotranspiration is a distinct advantage of Thornthwaite's model. Potential ET is realized when soil moisture levels are near field capacity and water is readily available for plant use. Maximum crop yields are dependent upon the plant's

[2]Thornthwaite and Mather, Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance, Drexel Institute of Technology, 1957.

reaching potential ET. However, when the moisture level is lowered in the soil profile, it becomes increasingly difficult for the plant to generate its potential ET. Hence, the actual ET will approximate potential ET only when the soil moisture level is near or at field capacity. As the fields dry out, the crop will use less water and subsequent reduction in yields can be expected.

Using measurements of potential ET when the soils are at field capacity and actual ET as the fields dry out in modeling the soil moisture balance allow the calculations to approximate actual in-field conditions.

Thornthwaite's equation for calculating potential ET is as follows:

$$e=ct^a$$

where e = monthly ET in centimerers

t = mean monthly temperature

c and a are coefficients which vary from place to place depending upon factors of latitude and mean annual temperature.

Tables provided in Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance by Thornthwaite and Mather bypass the process of working with lengthy coefficients and exponents. A straight line function relating potential ET to available soil moisture permits actual ET to be determined.

Precipitation as well as temperature data (needed for ET calculations) were taken from official U.S Weather Bureau records provided by the

National Climatic Center in Asheville, North Carolina. Daily records were available for nine stations either in or very close to Region 6E. This data, stored on computer tapes, contained 19-28 years of information depending on the station. Daily and seasonal average precipitation values were computed for each station using the available years of record. This calculation assigned some rainfall to each day during the growing season. Since in reality this condition doesn't occur, it was necessary to establish "raindays" at determined intervals during the growing season. Using probability figures (based on all years of record for each station), the precipitation that fell on any given day allowed these raindays to be determined. For example, if the probability of rain for days 1,2, and 3 were 20%, 50% and 40% respectively, day 3 was designated the rainday because the total probabilities exceeded 100% on the third day. The average rainfall calculated for days 1, 2, and 3 was totalled and that was considered to have falled entirely on day 3 as well. Starting over on day 4 with this cumulative process of adding probabilities allowed regional raindays to be established throughout the growing season with appropriate precipitation levels for each station.

Two levels of precipitation were used in calculating the soil moisture balance and determining subsequent drought. First used were the average rainfall figures, the precipitation expected 50% of the time or 5 years in 10. Used second was the rainfall expected in a dry year (precipitation expected 8 years in 10) where the probability figure is 80%.

Factors of runoff were not considered in the water balance computations. Losses due to runoff are dependent upon such variables as slope, infiltration rates, and vegetative cover which are difficult to evaluate for modeling purposes. Therefore, all recorded rainfall received during the growing season was considered to be "effective" precipitation and available for plant use.

<u>Available moisture holding capacity of the soil</u>. The following discussion on available soil moisture was taken from Blake et al.

> The capacity of the root zone to supply moisture for plants depends on the storage capacity of the soil and the depth of rooting of the crop.
>
> The storage capacity of different soils depends primarily on their textures--that is, the relative proportion of clay, silt, and sand. Fine-textured soils have greater storage capacities than sandy soils.
>
> When soils are thoroughly wet, the excess water drains downward into the ground water. Drainage greatly decreases after 24 to 48 hours, and the soil holds an amount of water called its field capacity. This amount varies for different soils. If a crop is growing on the soil and it receives no additional water, the moisture supply is slowly depleted until finally the plant wilts and dies. The amount remaining in the soil at this stage is called the permanent wilting percentage.

The necessary information regarding soil types in the study area and their respective ability to hold water was taken from the St. Cloud and New Ulm sheets of the Minnesota Soils Atlas.[3] The soils range from sands with a holding capacity of about 4 inches to heavy loams having a capacity of 8-12 inches. In all, eighteen soil types (or soil landscape units as they are called in the Soil Atlas) are identified on 12 different geomorphic regions in the study area. However, all of these soils are represented by 4 ranges of soil water holding capacity.

[3]Agricultural Experiment Station, <u>The Minnesota Soil Atlas</u>, University of Minnesota.

Table 1: Available soil moisture in representative soil types

Range of Soil Water Holding Capacity	Average Value	Representative Soil Landscape Unit
4 inches	4 inches	SSWL, SSWD
4-8 inches	6 inches	SLWD, RLWD, SLPD
6-10 inches	8 inches	XLWD, ALLUVIAL
8-12 inches	10 inches	LLWD, LL[illegible]L, LLPD LCPD, CLWD, LCWD
no value	-----	Peats and Marsh

The above figures represent the approximate amount of moisture which can be held in the individual soil profiles to a depth of 5 feet. Since the principal crop in the study region is corn which routinely roots to this 5 foot depth, the water holding capacity of the entire profile was considered in the computations. In this analysis the average value was considered rather than the range.

The soil moisture balance was calculated on a daily basis for each group of soils having a different rooting zone holding capacity. This meant an individual calculation for each day (153 days in the growing season) for the separate soil types using the climatic data of each station.

Two sets of seasonal computations were made using the combinations of the following conditions:

A. 75% recharge of the soil rooting zone and average rainfall

B. 75% recharge of the soil rooting zone and dry year rainfall

These combinations are just two examples of the conditions which might be encountered during a growing season. They provide a general insight into the occurrence of drought as these conditions vary. The 80% rainfall level used to model a dry year is consistent with the procedure used by the Soil Conservation Service. The 75% recharge level of the rooting zone allows for a common condition where pre-planting precipitation does not recharge the soil profile to capacity. It should be noted that the model is readily adaptable to a variety of situations and the two considered here were selected for demonstration purposes.

The equation used to calculate the daily soil moisture balance is shown below:

Soil Moisture Level + Precipitation - Evapotranspiration = Soil Moisture Balance

The soil moisture balance determined for day 1 becomes the soil moisture level from which the equation begins for day 2 and so on through the growing season. At no time is the soil moisture allowed to fall below wilting point or to exceed field capacity (100% recharge). Rainfall contributions which exceeded field capacity were considered lost by surface runoff or deep percolation. Drought days were designated when the computations showed no available soil moisture. The day when drought began as well as the number of drought days accumulated during the growing season were recorded for each soil group using the two different levels of precipitation and 75% recharge. These results were used to map drought prone soils, timing of drought and projected water deficiencies in the study area.

When drought occurred, the crop water shortages were determined. Examination of the potential ET (what the crop would use if available) and soil moisture contributions (precipitation and winter recharge) allowed the additional water needs of the crop to be computed.

Irrigation needs are determined by adding calculations of precipitation and sprinkler system efficiency to the crop water shortage estimate provided by the crop stress model.

The crop stress model assumes 100% precipitation efficiency in its estimates of crop water shortage. It is necessary to calculate a more realistic situation where rainfall is not totally effective to get a better estimate of irrigation actually required to supplement natural precipitation. This came from a table of average monthly effective rainfall as related to mean monthly rainfall and average monthly consumptive use.[4]

Sprinkler irrigation systems were assumed 1) to be the only method of irrigation in the study area and 2) to be 75% efficient. This was decided as an average efficiency of sprinkler systems in this area after discussions with the Agricultural Extension Service at the University of Minnesota.

[4]Irrigation Water requirements, Tech. Release 21, USDA SCS Eng. Div., April 1967 (revised Sept. 1970).

II. IDENTIFICATION OF POTENTIAL IRRIGABLE LANDS

The crop stress model identifies the occurrence of drought given information of climatic conditions, crop type, and the soil moisture holding capacity. In this pilot study the crop type was assumed to be corn in all calculations and uniform climatic conditions were applied to the study area for each iteration (day) of the model. This allowed for the variability of drought occurrence to be identified by soil groups of various soil moisture holding capacities. The Minnesota soil Atlas was used to map and identify these soil groups.

The Minnesota Soil Atlas is a cooperative project conducted by the Department of Soil Science, University of Minnesota, and the U.S. Soil Conservation Service. The Atlas provides basic soil information for broad land use planning purposes. It is not intended to replace the more detailed soil survey reports, but rather to provide necessary soil information until the surveys can be completed. Where available, SCS surveys have been utilized in the development of the Minnesota Soil Atlas. The mapping unit designed for use in the Atlas series is called the soil landscape unit. This unit is designed to help the used with a minimum knowledge of soils to readily understand the basic properties of the mapped soils such as soil texture, drainage conditions and soil color. The smallest area shown in the Atlas for which reliable information is available is approximately 600 acres. This should be kept in mind when looking at maps in this study which use the Minnesota Soil Atlas soil groups as mapping units. There is some variability to soil group boundaries and with data generalized to 40 acre parcels the information displayed cannot be considered site specific.

Drought occurrence by soil group is not the only factor looked at in the identification of areas having potential for irrigation. Land use and ownership restrictions of agriculture can be added to the drought prone areas data. These restrictions can vary from area to area to the state. Protection of woodlands, for example, is not as important in some areas as others. In some areas of the state acreage in public ownership can significantly alter estimates of potential irrigable land. In the study area, the minimal amount of urban and forested land uses in drought-prone areas resulted in the decision to consider only water and marsh land covers as restricted. Land ownership was not considered as a restriction in this pilot study.

The land use data in the MLMIS system is generalized to 40 acre data cells, compatible with public land records. Interpretation of high altitude aerial photography of the state from 1968 and 1969 was done and the dominant land use feature of each 40 acre cell classified into one of nine classes.

The MLMIS allows the overlaying of various data within the computer and in this manner the drought-prone areas interpretation of soils were overlayed with land use restrictions.

III. IDENTIFICATION OF ACREAGE CURRENTLY BEING IRRIGATED

The 1978 Mn. Department of Agriculture field survey of the irrigation for 22 counties was completed in three months. The counties included in the survey were chosen by three criteria. The seven metropolitan area counties were included because county proximity to home base allowed a close training ground for the student workers who did the survey. The dichotomy of urban and agricultural land uses in the metropolitan area provided additional incentive to survey these counties. The other 15 counties included in the field survey were previously identified by a 1977 MDA survey as having more than 2,000 acres irrigated per county. A similar survey was originally performed in 1975 using county field staff to identify the location and number of irrigated acres in the state. Meeker and Kandiyohi counties was included in this survey. The data collected in the field survey included:

1) Irrigated field location
2) Acreage estimate
3) Crop grown
4) Type of irrigation

The coded data was entered into the MLMIS so three maps could be produced for each county showing:

1) Field size
2) Crop grown (primary agric. such as corn, specialty crop, or potatoes)
3) Distribution system used (center-pivot, other)

Another source of information on irrigation is the DNR water appropriation permit file. The Land Management Information Center (LMIC) was contracted by the MDA to compile irrigation data contained in the DNR permit files to make the data more readily accessible. Although some of the permit data had been computerized on three separate lists, the lists could not be cross-referenced nor did they include all pertinent data found in the permits.

The data entered into the MLMIS from the DNR files include acreage, source of appropriated water, and location. The data are available for both tabulation and mapping and were used with the 1978 field survey data. The data from both surveys are complementary in that the windshield survey shows where irrigation is occurring on parcels also covered by appropriation permits.

The accuracy of the irrigation location data, in map and tabular form, is limited by several factors so that further use of maps of irrigation locations must be qualified according to the specificity of data used. Irrigated acres in the permits and field survey or irrigated acreage estimates may not be indicative of activity in any given year. Irrigation is a dynamic process, constantly changing in response to natural phenomena such as weather, soil condition and crop rotations. A field may be irrigated two out of three seasons or three out of five seasons. The field survey and permit data were interpreted with the assumption that irrigation occurs every year.

Acreage stated in the permit and field survey was interpolated into 40 acre parcels for coding purposes, meaning a 10 acre parcel appears as a full 40 acres.

Coding and keypunching errors were calculated using an error check of every tenth permit. An error level probability of P (.0062) or 0.62% was found in this manner. Missing permits were also a source of error calculated at less then 3 % of all permits. Permits were unavailable because of (1) processing, (2) microfilming, and (3) misplacement.

Refinements in the mapped and tabulated irrigated acreage data could have been achieved by using the annual pumpage reports required by the DNR from all irrigators. However, this important information is filed separately from the permits; to retrieve it requires an additional commitment of money and effort. Unfortunately, these resources were not available.

IV. GROUNDWATER AVAILABILITY

The Minnesota Department of Natural Resources Division of Waters and the Minnesota Geological Survey were asked to provide data and prepare maps to determine potential groundwater yield to wells for the Region 6E irrigation demonstration project. The Minnesota Geological Survey provided the Division of Waters with computer printouts of their well log data base for Kandiyohi, Meeker, McLeod, and Renville counties. The Division of Waters provided information from their permit files and from their aquifer data base. High capacity well data, such as location and depth, were field or phone-checked by Groundwater Group personnel.

The major source of information used by the MGS in compilation of data for its Subsurface Geology Data Base is records prepared by water well drillers. Drillers have been required to submit drilling records for new water wells to the Minnesota Health Department since the implementation of the 1973 Water Well Contractors Licensing Act in 1975. A copy of each record submitted is received by the Minnesota Geological Survey.

Before the compulsory filing of records on new water wells, contractors did keep records for their own use in repairing or modifying wells and as predictive aids in drilling new wells. Consequently, many, but not all, contractors possess files containing records of wells drilled over a span of many years. These so-called "historic" records form the largest body of geologic observations available for many parts of Minnesota. They are particularly important for bedrock geology and hydrogeology because so much of the state is covered with glacial deposits. Therefore, in spite of the problems of dealing with such variable records, the MGS has canvassed all of the state's water well contractors and obtained photocopies of virtually all useful historic records for its water well data base.

Both historic and new water well records contain information of some or all of the following kinds:

1) Geographic location
2) Well ownership and address
3) Well use
4) Pumping test results. Includes pumping rate, duration, and drawdown
5) Well construction. Geologically useful in determining the aquifer used
6) Static water level
7) Log containing depth intervals and descriptions of the materials encountered during drilling

The initial maps (location, depth, static water level, etc.) provided by the MGS were produced by computer plotter. These maps gave an overview of hydrogeologic conditions in the rgion but could not be directly interpreted into potential yield maps. Although there were a large number of well logs available, aquifer delineation was found to be difficult and more time-consuming than first visualized for several reasons:

1) The well logs were not from a planned and controlled drilling program

2) Many of the wells had unreliable hydrologic information
3) Aquifer boundaries could not be accurately defined.

The data shown in Maps 4, 5 and 6 were entered into MLMIS and are displayed using computer graphics techniques. The Division of Waters Ground Water Group manually prepared a series of maps from the data of each production zone:

1) "Structure contour" maps depicting the elevation above sea level of the upper surface of each buried zone. The contour lines were drawn on the elevation of the sand from which individual wells produced or from sand bodies documented in the well logs and occurring within the elevation range of each zone.

2) Water level contour maps for each zone. The range in water level elevations for all well logs was narrow, thus precluding zone or aquifer differentiation by potentiometric surface. The exception is the surficial zone where hydrogeologic data indicates water table conditions.

3) Maps showing available head in each zone. The available artesian head was calculated using the difference between static water level and the top of the production zone. Available head in water table conditions was calculated as two-thirds the saturated thickness.

4) Specific capacity maps. The specific capacity of individual wells was calculated when discharge and drawdown data were available. The specific capacity (Q/S) is defined as discharge divided by drawdown in a well and is expressed here as gallons per minute (discharge) per foot of drawdown. The data for these maps were sparse so a radius of influence of one-half mile around the given well was assumed.

It was hoped that the question of potential groundwater use conflicts could be investigated. Potential well interference maps were produced but these maps are very generalized and don't take the additive nature of drawdown into account. The maps could be used to define areas where present day well interference potential exists, but they can't be interpreted quantitatively. A meaningful well interference map can't be developed without accurate aquifer delineation.