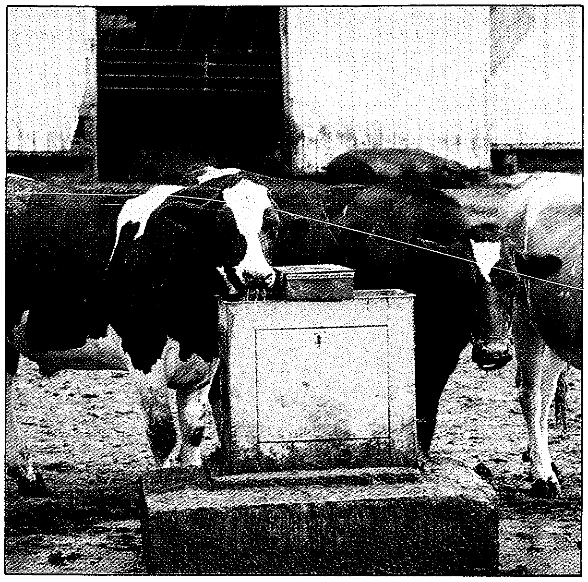
Water Use in Minnesota Agriculture



MINNESOTA DEPARTMENT OF NATURAL RESOURCES

DIVISION OF WATERS

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Water Use in Minnesota Agriculture

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Water Use
in Minnesota Agriculture

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Table of Contents

Page

List of Tables

List of Figures

allow for use by others. Unlike most western states, no different rights exist due to the length of time a prior user has appropriated water or the physical setting of the land relative to the water source.

Minnesota water law is administered by the Department of Natural Resources (DNR) Division of Waters through its water appropriation permit program. A permit is required for the taking of more than ten thousand gallons of water per day or one million gallons per year. These minimums exclude only the smallest users of water, such as most livestock watering systems. The law also exempts all private domestic supply systems serving fewer than twenty-five people. The amount of water authorized by a permit is dependent upon the intended use, other appropriators from the source, and the ability of the source to provide water.

Once issued, a permit remains in effect until terminated by the DNR. All permit holders are required to record the volumes of water used each month and report these amounts annually. These reports become the primary source of data for monitoring water use within the state. Analysis of reported use can identify trends in withdrawals which could indicate potential conflicts over limited water supplies. Similarly, examination of past years' reports can identify local water needs when conflicts do arise.

The primary role of the DNR in managing the waters of the state is to assure supply adequate to meet the long range requirements for all water uses. Where these uses conflict, the DNR must allocate water according to the priorities established by the state legislature.

In descending order, these priorities are:

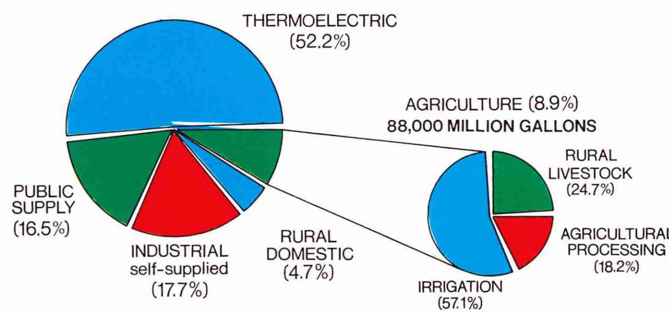
1) **Domestic water supply, excluding industrial and commercial uses of municipal water supply;**
2) **Any use of water that involves consumption of less than 10,000 gallons per day. For purposes of this section consumption shall mean water withdrawn from a supply which is lost for immediate further use in the area;**
3) **Agricultural irrigation, involving consumption in excess of 10,000 gallons per day, and processing of agricultural products;**
4) **Power production, involving consumption in excess of 10,000 gallons per day.**
5) **Other uses, involving consumption in excess of 10,000 gallons per day.**

Agricultural production is a high priority under these rankings. Virtually all livestock operations would fall under priority two; irrigation and agricultural processing follow under priority three. All agricultural uses are given priority before electric power generation or any other major industrial or commercial use. Water for domestic purposes is the only major consumptive use which has a higher priority than agricultural use.

Obviously, withdrawals can be limited by the volumes of water available. Ground water is generally available throughout the state, although not always in sufficient quantity and quality for agricultural use. Surface water in lakes and streams is available to riparian owners, but withdrawals are limited by the need to maintain adequate water levels for fish and wildlife habitats and other instream uses.

Figure 1. Minnesota Water Withdrawal in 1985

TOTAL 995,000 MILLION GALLONS



Almost one trillion gallons of water were withdrawn from Minnesota lakes, streams, ponds, quarries, and wells in 1985 (Figure 1). Of this amount, almost nine percent was used for agricultural production. Electric utilities used the largest volumes of water, primarily for cooling at their power generation plants. Unlike most agricultural uses of water, however, a significant portion of the water taken by electric utilities is returned to the river or lake from which it came. Irrigation, livestock production, and many agricultural processing operations do not return much of the water taken from the source. Thus, this water is no longer available for use downstream or (for ground water sources) by other well owners. Agricultural production accounts for about 23 percent of all water consumed in the state.

INTRODUCTION

This report examines the use of water for agricultural production in Minnesota. Three major categories of use will be discussed: water for irrigation of cropland, water for processing of agricultural products, and water for consumption by livestock.

For each category, this report describes the ways in which water is used, the location of the water users within the state, the total volume of water required for production, and any trends which have been identified in past or present use. A description of current and potential ground water sources for irrigation is included.

When water is withdrawn from a well, a lake, or a stream, there is some impact, however small, on the resource. This impact can be magnified many times over if the amount of withdrawal is large, or if many users take water from the same source, or if the characteristics of the water -- its chemistry or temperature -- is altered by its use.

This report will look at some of the impacts of agricultural production on the surface and ground waters of the state. It will examine the effects on both the quantity of water available and on the quality of this water. It also describes the DNR's role in resolving some of the problems associated with the use of water.

The purposes of this report are threefold:

1) To provide information to policy makers, the industries being described, and the general public regarding the need for water in agricultural production,

2) To stress the need for proper resource management in order to ensure that adequate quantities of good quality water are available to an important sector of the Minnesota economy, and

3) To describe the Department of Natural Resources' (DNR) role in managing the use of the waters of the state among all competing uses.

Water is one of Minnesota's greatest assets. We are the land of 10,000 lakes (actually closer to 15,000 at last count); birthplace of the mighty Mississippi River; and neighbor to Lake Superior, the largest freshwater body in the world. To Minnesota, water means fishing for walleye on Mille Lacs Lake, hunting waterfowl in Lac Qui Parle Wildlife Area, paddling across Saganaga Lake in the Boundary Waters Canoe Area, or just enjoying the sunset from a cabin on Otter Tail Lake.

Water plays an important role in Minnesota industry. It helps turn iron ore into steel, wood into paper, and limestone into concrete. It cools the turbines at Prairie Island Nuclear Power Plant. It can also change a barren field into lush green rows of corn, provide drink for a flock of turkeys, or turn milk into cheddar cheese.

In fact, water is so important to Minnesota that we dare not take it for granted. Nature likes to remind us of this from time to time -- holding back the water for months, as in the drought of the 1930's, or flooding lakes and fields in the 1980's.

Even in years of normal rainfall, we find that the numerous demands we place on our water resources can work against each other. Draining a wetland to plant crops can destroy a prime [illegible]ing area for waterfowl. Hazardous waste dumped into a stream can ruin a good fishing hole. Pumping thousands of gallons per minute from a well may affect the drinking water supply for the farmer down the road.

A concern for protecting and preserving our water supplies prompted the Minnesota state legislature to pass laws regulating the use of water in 1934. The immediate problem at the time was the drought, which was having a devastating effect on the lives of many Minnesotans. The legislature chose to fashion state water law after "Eastern" water law, which is based on riparian rights to the water source. The right to make use of water is limited to the owner of the land adjacent to, or in the case of ground water, overlying the source. In Minnesota, riparian rights are tempered by the concept of *reasonable use*, which means that the riparian owner may use the water subject to the equal right of all other owners to use the water for similar purposes. If there is not sufficient water to supply all demands, each riparian owner must control his/her own use to

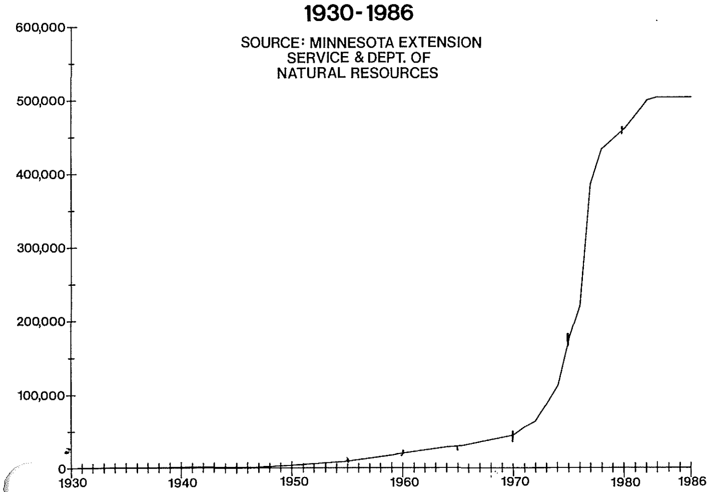
AGRICULTURAL IRRIGATION

In Minnesota, irrigation is used to supplement natural rainfall in order to increase crop yields. Extended periods of low rainfall are rare in the state. However, short dry periods are common in the summer months when crops are sensitive to a lack of moisture. Irrigation during these times can reduce the amount of stress on the plants and optimize crop production. This is particularly true in areas with sandy soils, which have low moisture holding capacity.

TRENDS IN IRRIGATION USE

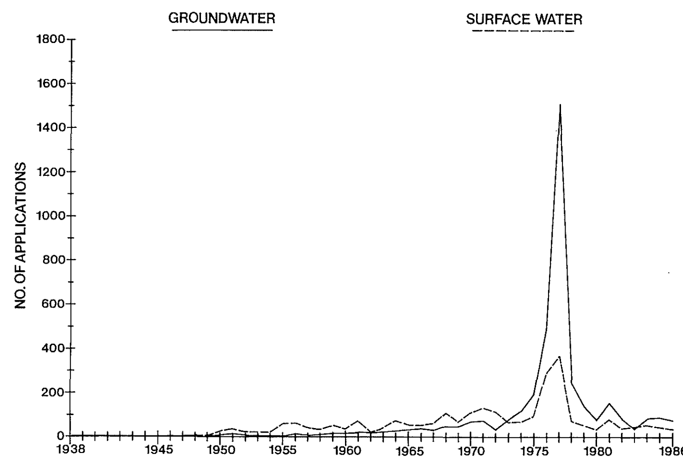
The earliest known records of irrigation in the state refer to a few truck farmers who sold their vegetables and fruit in the Twin Cities area during the early 1920's. At the same time, some sugar beet and potato growers tried irrigation in the Red River Valley. Even during the drought of the 1930's, there was little increase in the use of irrigation (Figure 2). By 1941, 250 Minnesota farmers were irrigating 1,500 acres of land. After a lull during the war years, the number of acres increased slowly during the late 1940's and the 1950's to about 20,000 acres in the early 1960's. Most of the irrigated acreage at this time was centered in Sherburne and Dakota Counties - areas with sandy soils, ample water supplies, and a major market, the Twin Cities metropolitan area, nearby. Still, the total amount of irrigated acreage amounted to less than one-half of one percent of all cultivated acres in the state (The Potential for Irrigated Cropland, 1976).

Figure 2. Minnesota Irrigated Crop Acreage 1930-1986



A small shift in the use of irrigation began during the 1960's. Before this time, most irrigators in the state withdrew water from lakes or streams rather than from wells. Between 1934 and 1960, the DNR received four times as many applications for surface water permits as ground water permits. By 1970, the ratio had been reduced to two-to-one. Between 1973 and 1986, the number of ground water permit applications has been more than twice the number of surface water applications (Figure 3).

Figure 3. Irrigation Permit Applications 1938-1986

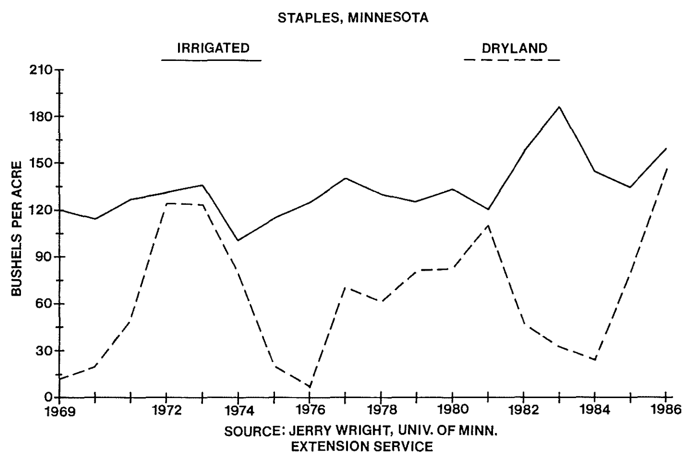


Although the cost of drilling a well makes it more expensive than surface water, the use of ground water offers two distinct advantages. First, irrigation water is most needed during hot summer months when surface waters tend to be at their lowest levels. Ground water sources remain more stable in relation to seasonal changes in precipitation. Second, irrigators can only use surface water if they are riparian (adjacent) to a stream or lake. Aquifers capable of yielding sufficient quantities of water for irrigation are common in many parts of the state, making irrigation a viable option for a much larger number of farmers.

The years 1976 and 1977 mark a major increase in the use of irrigation in Minnesota. The number of DNR permit applications jumped from 292 in 1975 to 782 in 1976 and 1,978 in 1977. This increase came in response to extremely low precipitation. In fact, the period from April to August 1976 was the fourth driest on record. Faced with the prospect of losing their entire crop, farmers looked at irrigation as a form of insurance to protect their investment.

Once the capital investment in irrigation equipment was made, however, many farmers changed their attitude toward the use of irrigation. They found that the timely application of water to their crops could improve their yields, even in normal-to-wet years (Figure 4). The use of irrigation also improved the efficiency of their other production inputs, such as fertilizer and pesticides. Instead of merely being a hedge against drought, irrigation became a part of their total crop management system.

Figure 4. Irrigated vs. Dryland Corn Yields



To some extent, the number of DNR permit applications shown in Figure 3 exaggerates the increase in the use of irrigation during the 1976-1977 drought. Many farmers who received a DNR permit never installed an irrigation system. Some farmers postponed their plans to irrigate when the rains returned in 1977. Others, possibly confused by the vagueness of Minnesota water law at the time, acted on the mistaken assumption that the DNR would limit the number of appropriation permits that would be issued. Others believed they should obtain a permit in order to maintain their rights under a prior appropriation doctrine. In 1977, the state legislature acted to clarify the DNR's responsibilities and the rights of water users in a major revision of Minnesota Statutes Chapter 105, which covers water appropriation and the permitting programs. Further clarification came with the revision of agency rules regarding water appropriation.

Between 1977 and 1982, the use of irrigation continued to grow, although at a slower pace than during the drought. Crop prices remained stable at a fairly high level, so farmers were able to justify the greater expense of irrigation in order to achieve greater yields and higher revenues. Since 1982, there has been little increase in irrigation in Minnesota. This is a result of the fall in crop prices, which has reduced the incentive to invest in expensive equipment to increase yields. Moreover, the fall in prices led to a decline in land values in the state (see Table 1), which in turn reduced farmers' borrowing power for obtaining loans for capital investment.

Table 1: Average Value of Minnesota Farmland.

Year	$/Acre
1973	298
1974	423
1975	525
1976	667
1977	794
1978	889
1979	1,040
1980	1,120
1981	1,310
1982	1,179
1983	927
1984	927
1985	686

Source: Minnesota Department of Agriculture, 1986.

Another trend which began during the mid-1970's was the irrigation of fine soils in Minnesota. Once again, many farmers were probably influenced by the drought and the threat of crop loss. However, the greater water holding capacity of finer soils makes them more resistant to drought as well as more susceptible to overwatering. As Table 2 shows, irrigation of finer soils produces a smaller percentage increase in yield than irrigation of coarse soils, although the total yield potential is greater.

The use of irrigation can only account for a portion of the increase in yields exhibited here, because crop management practices change when irrigation is used. More fertilizer is applied, higher seeding rates are used, and different tillage practices may be implemented. Nevertheless, irrigation of finer soils has been shown to increase yields, in addition to its benefits as insurance against crop failures.

Table 2: Field Corn and Soybean Yields.

Average yields (Bushels/Acre)

Available Water Capacity*	Field Corn			Soybeans		
	Non-Irrigated	Irrigated	% Increase	Non-Irrigated	Irrigated	% Increase
Moderate (6-9 in.)	76	141	86%	34	45	32%
High (9-12 in.)	104	150	44%	41.5	52	25%
Very High (>12 in.)	108	152	41%	40	53	33%

* *Moderate* = *medium sand to sandy loam*
High = *sandy loam*
Very High = *loam to clay*

Source: *Survey of farmers in southwestern Minnesota for 1977 and 1978*
Wilson and Eidman, (1981)

CURRENT IRRIGATION IN MINNESOTA

The DNR and the University of Minnesota Extension Service are the two main sources of information on the use of irrigation in Minnesota. Their estimates of the amount of irrigation in the state differ, however, because they use different aggregation methods. From 1970 until 1976, the Extension Service conducted its own surveys of irrigators in the state. This practice ceased when the number of irrigators increased dramatically during the drought. Since then, the Extension Service uses more informal contacts with sample farmers and supplements this information with estimates based on the number of irrigation permits issued by the DNR each year. Unfortunately, many farmers applied for DNR appropriation permits in 1976 or 1977 and never installed an irrigation system, or installed a system and never used it. Thus, the Extension Service may have overestimated irrigation use since 1976.

The DNR obtains first-hand data from irrigators each year through the water use reporting process. However, aggregations of these data underestimate irrigation in the state because some permit holders do not report their use and other irrigators do not have a DNR appropriation permit. On average, 10 to 15 percent of permitted irrigators do not submit water use report forms, and an unknown number of irrigators do not have a permit. Thus, the DNR irrigation totals are low, although some effort is made to estimate water use by non-reporting but permitted water users.

At present, there is no way to reconcile the discrepancy between the two sources of data, and both totals are presented here. Over the last ten years, the DNR has taken several steps to improve the permitting program and, indirectly, its water use data collection. First, permits are not issued until the agency has documentation, in the form of a driller's well log, that a well has been drilled, thus ensuring the commitment of the permit holders to use water. Second, the Department of Health provides one copy of all well logs to the DNR. This is an independent identification of all new irrigation in the state. Third, the DNR has expanded its efforts in tracking down permit holders who do not report their use. Fourth, computerization of all permit data has enabled the DNR to identify permit holders who are delinquent in their reporting of water use.

An increase in the annual permit processing fee in 1983 prompted a large number of requests for termination by permit holders who had never irrigated and now wished to avoid the new, higher costs. The list of active irrigators in the state now provides a more accurate reflection of actual irrigation in the state. A continued commitment to the permitting program and the collection and analysis of water use data at the DNR should ensure a steadily improving set of irrigation data in the future.

The total amount of water used and number of acres irrigated in Minnesota are shown in Table 3. These figures are based on DNR permit data. Wild rice is distinguished from all other crop irrigation because irrigation practices for this crop are markedly different from those of all other crops grown in the state.

The relative density of irrigation can be compared for each county in Figure 5. Dakota County has the largest amount of irrigation as a percentage of total land area, with an average of 67.1 acres per square mile (1985 acreage). Sherburne County is next with 53.3, followed by Pope (39.0), Swift (29.0), Benton (18.8), Stearns (17.7), Stevens (17.0) and Wadena (15.3) counties.

Table 3: Water Use for Irrigation - 1985.

	Ground water	Surface water	Total
Acres			
Crops*	250,740	25,805	276,545
Wild Rice	2	20,845	20,847
Acre-feet of Water			
Crops*	107,100	9,400	116,500
Wild Rice	20	33,930	33,950

* *All crops other than wild rice.*

Source: DNR Water Appropriation Permit Holders

Given that corn is the number one crop in the state, it is not surprising that it represents about half of all irrigated acreage (Figure 6). The yield response for corn is very good; application of moisture at key points of plant maturation virtually guarantees a substantial increase in bushels per acre. Nevertheless, most irrigated corn acreage is north of the primary corn producing counties, which are concentrated in the southern third of the state. Irrigation produces a much greater response in the sandy soils of Central Minnesota.

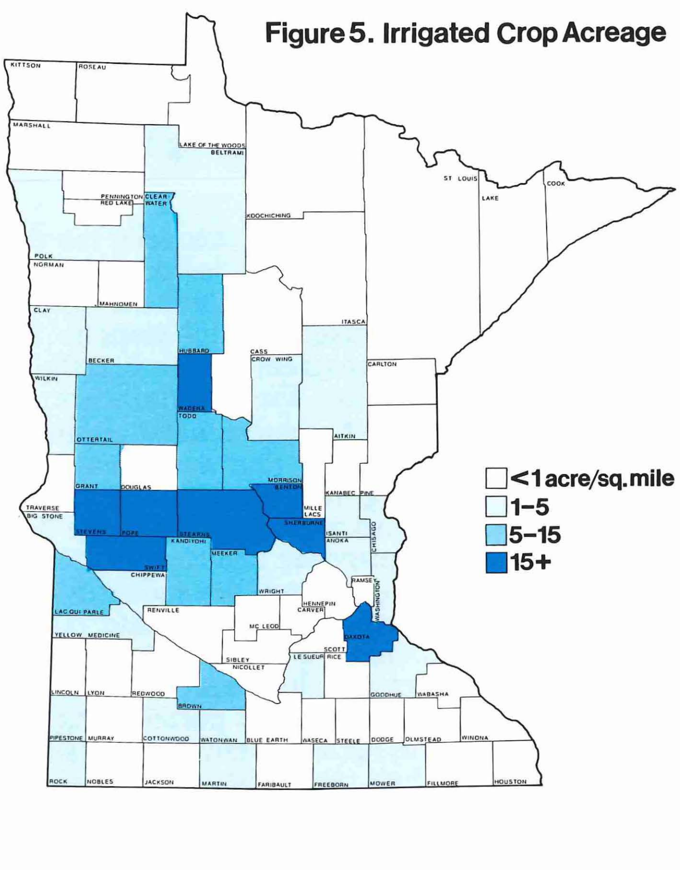


Figure 5. Irrigated Crop Acreage

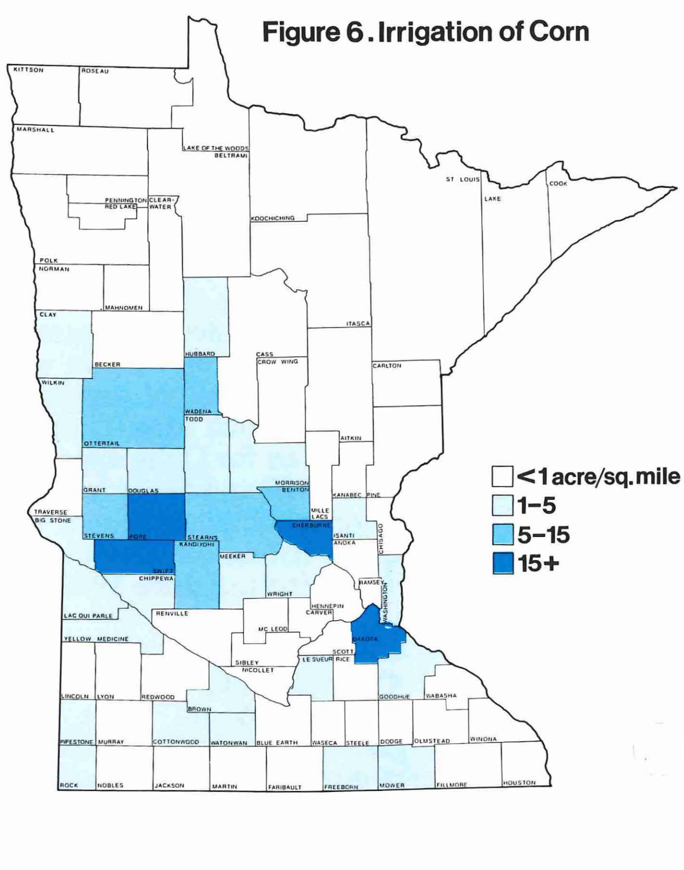


Figure 6. Irrigation of Corn

While soybean acreage ranks second in total irrigated acreage in the state, 40,000 irrigated acres account for less than one percent of all soybean acreage (Figure 7). Yield response is not as dramatic as the response for corn. The center of irrigated soybean acreage is slightly south of the center for corn; soybeans tend to hug the southern boundaries of the sandy soils.

Potato yields drop dramatically when moisture is not available. Irrigation is a necessity for potato farms on sandy soils. Virtually all the potato acreage in Sherburne, Benton, Todd, Pope and Hubbard counties is irrigated (Figure 8).

Wild rice is unique among agricultural crops in Minnesota. This native plant requires production techniques unlike those for any other crop. Paddy wild rice fields are flooded with up to eighteen inches of water in late fall or early spring. A water cover remains until midsummer, when the fields are drained and the crop is harvested. All wild rice acreage is in the north-central part of the state (Figure 9). Needless to say, all of the wild rice acreage is irrigated; virtually all of the water comes from surface water sources rather than from wells.

Figure 8. Irrigation of Potatoes

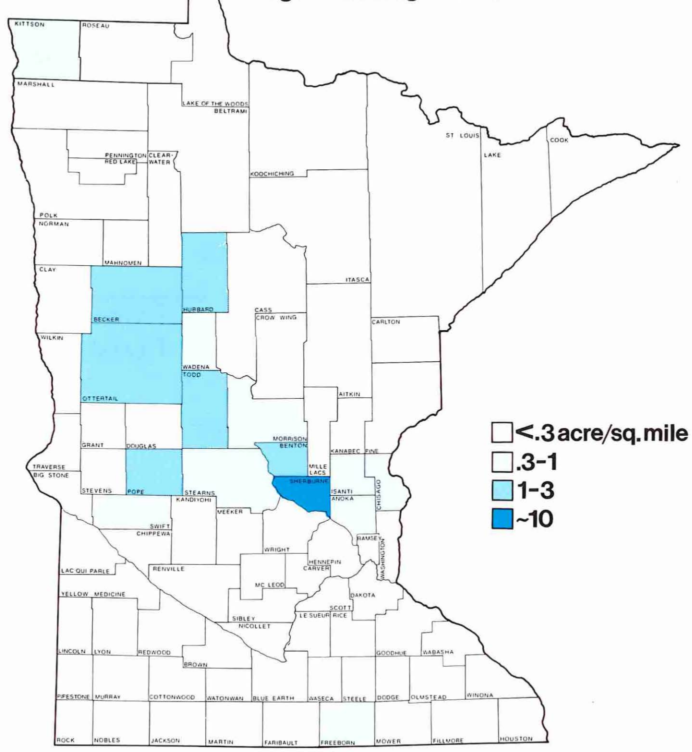


Figure 7. Irrigation of Soybeans

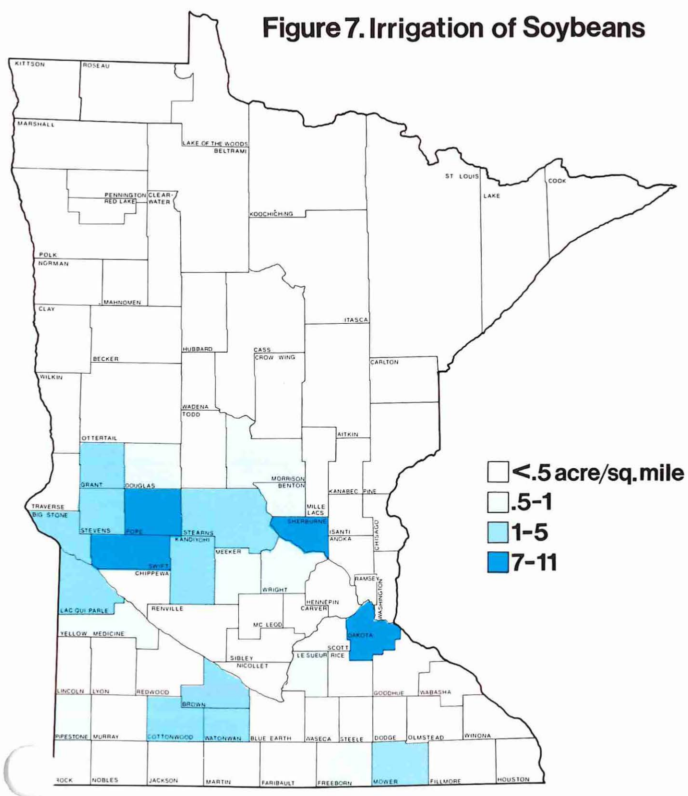


Figure 9. Irrigation of Wild Rice

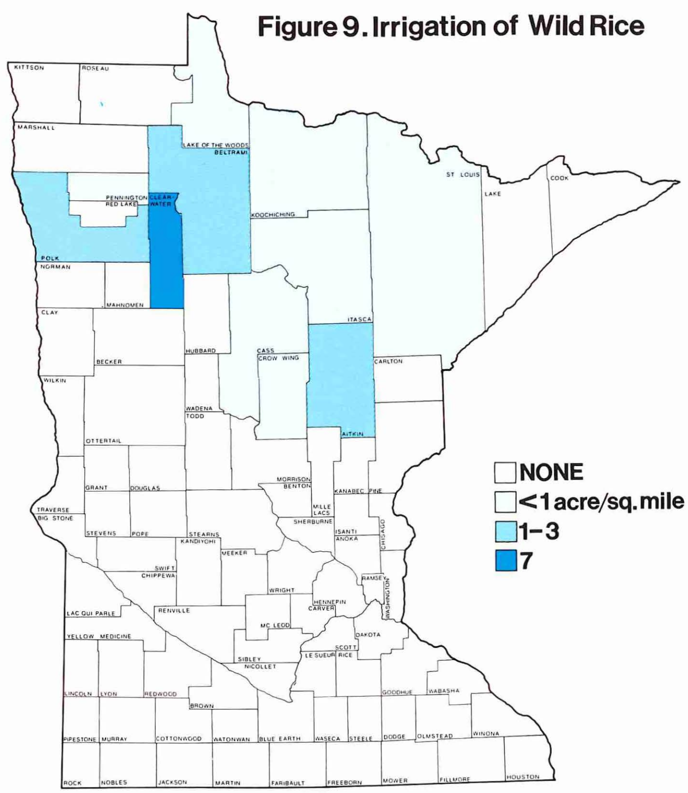


Table 4 compares the total number of acres cultivated to the number of acres irrigated for selected major crops grown in Minnesota. Corn accounts for over one-half of all irrigated acreage, although less than three percent of all corn is irrigated. As a percent of total acreage, irrigation is only significant for potatoes, dry beans, and wild rice.

Table 4: 1985 Crop Acreage for Major Crops

	Total Acres (1,000's)	Irrigated Acres (1,000's)	Percent of Total
Corn	7,300	158.4	2.2
Soybean	5,100	40.8	0.8
Field Crops	5,730	9.8	0.2
Alfalfa	1,825	19.7	1.1
Sugar Beets	278	1.1	0.4
Canning	211	9.7	4.6
Potatoes	85	19.1	22.5
Dry Beans	68	12.8	18.8
Wild Rice	20.9	20.9	100.0
Total acreage irrigated:			297,641

Source: *DNR permit records and Minnesota Department of Agriculture (1986).*

DNR water use data can also be used to analyze changes in water needs under various conditions in Minnesota. To demonstrate how this data can be used, the DNR chose to examine three factors which influence the amount of water used for irrigation: precipitation, soil type, and crop grown. These variables have significant impacts on irrigation water requirements, and evidence of these impacts may be useful. Water use reports for this study were taken from a sample of irrigators located in West Central Minnesota. While other factors, such as the efficiency of the irrigation system or the experience of the irrigator, may influence the amount of water applied, these variables are much more difficult to analyze.

Analysis of three commonly irrigated soil types revealed some significant differences in water needs. The average amount of water applied to loamy over sandy, well-drained, dark soils was 6.3 inches per acre. Deep silty, loamy, well-drained soils averaged nearly the same amount, 6.2 inches per acre. Not surprisingly, coarse, sandy, well-drained, dark soils required 12.4 inches, about twice as much water as the finer soils.

Our sample provided enough data to analyze water requirements for only two major crops in West Central Minnesota. The average amount of water applied to corn was 6.36 inches per acre, and potatoes averaged 9.95 inches per acre. In comparison, wild rice irrigation used 19.5 inches per acre, based on statewide pumpage data for 1985.

The analysis of precipitation and irrigation showed no significant difference in the amount of water applied for varying levels of rainfall. This was the case for both annual and May-to-September rainfall amounts. In all samples, however, more water was used during dry periods (precipitation levels less than 15 inches) than during normal or wet periods.

While the results of these analyses are limited, they provide a sample of the information which can be obtained from reported pumpage data. They also show the need for further study of the impacts of soil, crop type, and rainfall on the amount of water used for irrigation.

CHANGES IN IRRIGATION PRACTICES

Over the past 20 years, Minnesota farmers have begun to apply new agronomic and irrigation technologies which have caused many positive changes in typical irrigation production systems. These changes include: 1) higher yields, 2) reduced application of irrigation water, 3) increased crop water use efficiency - (yield per unit of water), 4) reduced energy consumption, and 5) reduced manual labor requirements.

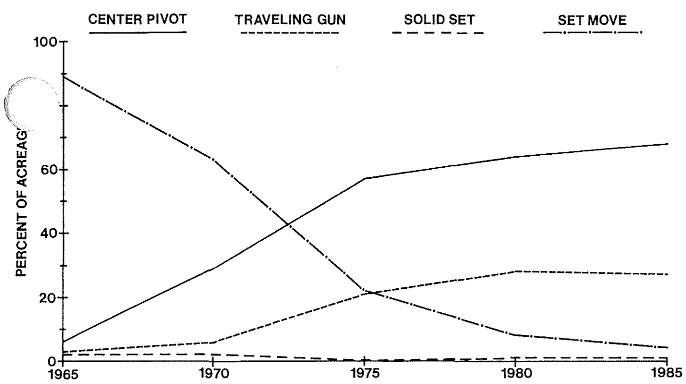
During this time, crop varieties and hybrids have improved, and cultural and water management practices have been refined. Self-propelled continuous move irrigation machines (center pivots and traveling guns) have been developed which require less labor and increase water application efficiency. These changes aided in the rapid expansion of newly irrigated acreage in the early 1970's.

Water application efficiency (WAE) is a relative expression of the uniformity of an irrigation system's water application distribution. It is the ratio of the average water applied that enters the soil to the total water that is pumped. An increase in this value means less water needs to be pumped to add the same amount of water to the soil over the irrigated area. For example, to add 1.0 inch of water (27,154 gallons per acre) to the soil with a 60% WAE system, 1.66 inches (45,257 gallons per acre) must be pumped, while an 85% WAE system needs to pump only 1.17 inches (31,770 gallons per acre). Thirty percent less water is used to produce the same crop.

Early hand move set systems like the single gun, boom, lateral line, or end tow line produced efficiencies in the range of 40 to 60 percent, whereas the self-propelled continuous move systems have efficiencies of 75 to 90 percent.

Figure 10 shows how the distribution of different irrigation systems in Minnesota has changed over the past two decades. Currently over 95 percent of the acreage is irrigated by continuous move equipment and three-quarters of this acreage is irrigated by center pivots.

Figure 10. Irrigation System Distribution



SOURCE: JERRY WRIGHT, UNIV. OF MINN. EXTENSION SERVICE, 1987
NOTE: SET MOVE INCLUDES HAND AND MECHANICAL MOVE EQUIPMENT

New and replacement sprinkler packages for center pivots are being selected by computer-aided programs to maximize their application uniformity to given sites. Slightly higher WAE's are obtainable by the use of some trickle irrigation systems. Trickle systems are not currently an economical method for conventional field crops in Minnesota and are best suited for high value horticultural crops. Approximately 1500 acres are irrigated by trickle systems in Minnesota.

Changes in irrigation water scheduling tools and management strategies have reduced water usage and increased crop water use efficiency for many crops. Irrigation scheduling is the decision-making practice of determining when and how much irrigation water should be applied to maintain healthy plant growth and optimize yields.

Prior to the 1970's, operators were encouraged to apply approximately 1 inch of water (less rainfall) to the soil every four days when a crop obtained full canopy cover and was in its most critical growth period. In the early 70's, many operators were encouraged to optimize their applications by monitoring their soil moisture status with soil moisture sensors like the tensiometer. Research from the University of Minnesota's irrigation research farms at Staples and Becker showed that this method would save around 15% in both water application and pumping expenses.

Further improvements in the analysis of soil moisture came in the mid-1970's with the introduction electrical resistance blocks and the use of soil moisture accounting methods to estimate crop water use rates. In 1978, the Minnesota Extension Service published its first edition of *Irrigation Scheduling - Checkbook Method*, which describes a method for determining water application rates and frequency based on daily maximum temperature and crop growth stage. Average water use tables are included for eight crops. The checkbook method had originally been developed for use in North Dakota. The Extension Service introduced the method to Minnesota after testing its applicability for corn, soybeans, and alfalfa at research stations in Becker, Staples, and Westport.

The University of Minnesota Department of Agricultural Engineering recalibrated these crop water use estimation tables for central Minnesota in 1985, reducing the previous crop water use estimations by 10 to 15 percent. In the spring of 1986 these new tables were placed in a revised version of *Irrigation Scheduling - Checkbook Method*.

Minnesota Extension agricultural engineers estimate that the improvements in irrigation scheduling have had the cumulative effect of reducing water use by 30 to 50 percent. Producers who used to apply 12 to 15 inches of irrigation water to corn are now using only 6 to 9 inches. Future irrigation water scheduling tools will incorporate on-farm personal computers, plant-based water stress monitors such as infrared thermometry, and computer-operated irrigation systems.

IRRIGATION SOIL AND WATER NEEDS

Long term success for any irrigation project requires suitable soil conditions and a dependable water supply. The majority of Minnesota irrigation occurs in the central outwash plains which provide excellent soil drainage and large quantities of high quality water from buried and surficial aquifers.

In a normal year, more than half of the annual precipitation falls during the May to August growing season. Even so, available moisture is likely to be insufficient at some time for many crops. To lessen the possibility of yield reductions resulting from moisture stress, irrigation systems are used to augment natural rainfall amounts.

Irrigation, which is often perceived as a simple solution to the problem of variable timing of rainfall, is not as simple as turning on the sprinklers. From an agronomic and economic perspective, installation and operation of an irrigation system requires knowledge of appropriate timing and volume of water applications.

Any water to be applied to a field must first be lifted, pressurized, and transported to the distribution system. Extensive energy requirements for each of these processes make superfluous irrigation an unwarranted expense. Judicious use of water will save an irrigator money, water, and time. Yields from a crop which has been irrigated indiscriminately are not likely to be higher than yields where irrigation was wisely used.

From an agronomic point of view, the impacts of excess or deficient water depend on the stage of development of the crop. For example, the development of roots is dependent upon the stimulus of wet soil. Since root hairs will not grow into a dry soil, dry conditions early in root development will lead to a smaller root system which later may prove incapable of taking up enough water, even under saturated conditions. Conversely, young plants growing in a soil which is too wet will develop a shallow root system which will need more frequent waterings to keep moisture available. A surplus of water during the vegetative growth period, though resulting in an apparently prosperous field, actually lowers the overall grain yield by promoting excessive leaf area and lodging. If irrigated when 50 to 60 percent of the available soil moisture has been depleted, the plant will usually develop a large, deep root system and avoid any rooting problems (Stoskopf, 1981).

The number of applications and the amount of water used is not as important as the timing of irrigation. For example, corn is most vulnerable to moisture stress between the tassel and dough stages. When under stress, fertilization is shortened considerably and the result is an ear on which only the middle kernels have developed.

Two days of stress during silking can reduce corn yields 20 percent. Just four to eight days of stress can lead to yield reductions well over 50 percent (The Potential for Irrigated Crop Production, 1976). Maximum yields are reached when sufficient moisture is available beyond the dough stage and up until the time when the crop reaches physical maturity. Dough stage occurs in mid-August, and the crop can be considered mature in mid-September. After this 50-55 day (tassel to maturity) period and before tasseling begins, moisture stress appears to have less affect on the yield.

Obviously, the conditions and dates described above will vary with local climate, soils, and the particular hybrid planted, but wise application of water is necessary to obtain sufficient returns to justify the substantial costs of developing and operating an irrigation system.

Importance of Soils

Most irrigation in the state is centered in areas of outwash sands and gravels. Soils which form in such materials generally are well suited for irrigation. The texture of sandy soils tends to reduce available water due to the poor water holding capacity inherent in coarse soils. Although many other factors are involved, texture determines infiltration rate, movement, and retention of water in the soil.

A well drained soil warms more quickly in the spring, encourages root development, and prevents the unwanted accumulation of excess salts in the root zone. When high concentrations of sodium are allowed to accumulate, the physical structure of fine-textured soils can be affected. The breakdown of aggregates to finer sizes leads to poor hydraulic conductivity, poor infiltration, and, in severe cases, to development of an impermeable layer.

The University of Minnesota's Agricultural Experiment Station has rated areas of the state on the basis of land suitability for irrigation (Bather, 1976). Figure 11 shows areas where land has been classified as being most suitable, moderately suitable, and least suitable for irrigation. These determinations were based on available water capacity, drainage, topography, size and shape of irrigable areas, soil temperature, and current land use.

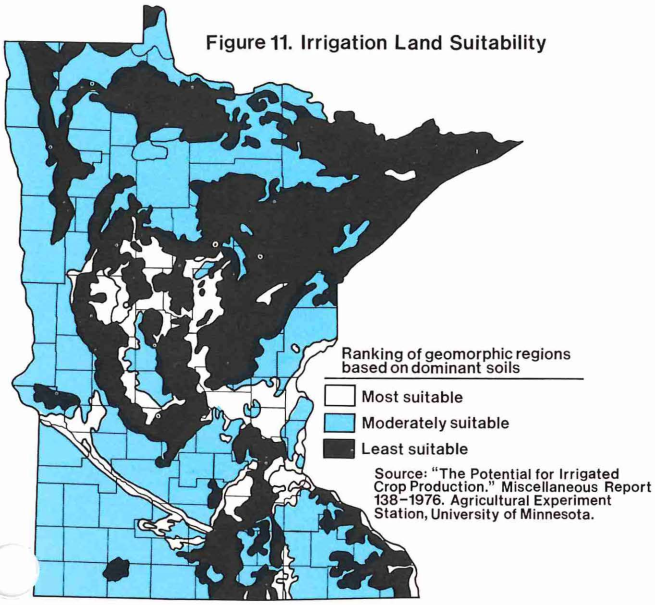


Figure 11. Irrigation Land Suitability

Soils judged to be most suitable for irrigation are primarily the outwash areas with a well-drained subsoil. Moderately suitable land, which comprises the majority of the agricultural land in the state, may have greater water holding capacity, poor drainage, generally steeper topography, or an existing land use which is inconsistent with irrigation development. Soils found to be least suitable for irrigation had excessive relief, poor drainage, shallow soils, or cool soil temperatures. Peatlands, fine-textured lacustrine and till plains, moraine complexes, and steep uplands are typical of these unsuitable areas.

The broad classifications are useful in the identification of potentially irrigable land on a regional basis in spite of being insufficient for determining the land suitability for a specific site. By combining this information with areas which have suitable water supplies it is possible to make a general assessment of potential irrigable lands in the state.

Water Availability

Minnesota is frequently described as being a "water-rich" state. The numerous lakes and streams, vast ground water reserves, and subhumid climate would suggest ample water availability. Water for crops, regardless of the source, must be of suitable quality and must be available when needed.

Whether ground water or surface water is used, the source must be capable of supplying good quality water at an acceptable rate. An irrigation water supply must provide sufficient water for peak use and for continuous use after allowing for economic constraints, resource limitations, and various legal restrictions such as higher priority users and other irrigators.

Table 5: Recommended System Capacities for Center Pivots

Soil Type	System Capacity (gpm)*
Gravels, coarse sands	900 - 1200
Fine sands, loamy sands, sandy loams	700 - 900
Loams, silt loams, clay loams	500 - 700

* Values based on 130 acres irrigated and an 85 percent application efficiency and a 22 hour per day operation. Peak daily water use range is 0.16 to 0.38 inches.

Source: Bergsrud, et al., 1982

Table 5 shows the recommended system capacities for various soils. The DNR's irrigation permits show a range of pumping rates from as low as 100 to as much as several thousand gallons per minute. The average pumping rate for all types of irrigation from ground and surface water is approximately 750 gallons per minute. Needs of individual systems will, of course, vary with local factors such as water source, specific crop requirements, and water management plans.

Irrigation Water Quality

All water, regardless of source, contains dissolved solids obtained from the materials the water flows over or through. Although not a major concern in Minnesota, there are areas where water of questionable quality is found. Primary water quality parameters used to determine irrigation suitability are soluble salts, sodium, and boron concentrations.

Use of fertilizer and irrigation water, both of which contain salts, may eventually increase the amount of soluble salts in the soil. Salt accumulates in the root zone when concentrated by evaporation and when present in excess of plant requirements. Periodic flushing of the root zone is necessary to leach out accumulated salts. Minnesota receives sufficient rainfall to leach the soil and artificial flushing is rarely needed except where poor quality water is used. It is essential that adequate drainage be available for salt removal if an irrigation system is to be successful over a period of years. Electric conductivities (an index of ion concentrations) of about 2,000 micromhos per centimeter are considered the upper limit for irrigation waters (provided that sodium concentrations are not great).

Where sodium is predominant, it can replace the calcium and magnesium which are bound to clay particles. Sodium causes clay particles to disperse and results in poor structure and greatly lowered infiltration and hydraulic conductivity rates -- particularly where a layer of clay accumulation (hard pan) has developed in the subsoil. Crops which cannot tolerate high sodium concentrations will usually be affected before concentrations become high enough to cause deterioration of soil structure (Wilcox, 1955). High sodium soils are reclaimed by leaching and addition of calcium and magnesium.

The presence of boron is required for normal plant growth, yet this minor nutrient becomes toxic to many crops at concentrations of 1.0 ppm or less. Boron toxicity is dependant upon the tolerance of the plant species and, in general, is enhanced in acidic soils.

Use of Surface Waters for Irrigation

In most areas of the state, the use of surface waters for irrigation supplies, though not prohibited, is discouraged. In addition to legal constraints associated with surface water appropriation, natural fluctuations of lake and river levels render these sources undependable. For example, water levels which were at or above ordinary high water levels in 1986 have declined rapidly in 1987 due to extremely low spring runoff and precipitation. This responsiveness to climate means that surface water may be unavailable when it is most needed for irrigation.

Where it is available, water from lakes and streams offers several advantages over ground water sources. Development of a surface water source is much less expensive because no well is needed. In addition, surface water quality is known and is generally suitable for irrigation throughout the state. System design is straightforward because the maximum pumping rate from surface water is determined by the equipment used, whereas the maximum pumping rate from ground water is determined by the hydraulic characteristics of the aquifer, which are not known in advance.

No significant patterns are discernible from a map of irrigation systems in the state which use surface water (Figure 12). The heaviest concentration of permits is in Wadena, Todd, and Sherburne counties. In Wadena county, most surface water irrigation is on or near the Crow Wing, Redeye, and Leaf Rivers in the southwest. About one-half of the surface water irrigators in the area take water from dug pits. In Todd county, irrigation follows the Long Prairie River. The primary sources in Sherburne county are the Mississippi and Elk Rivers.

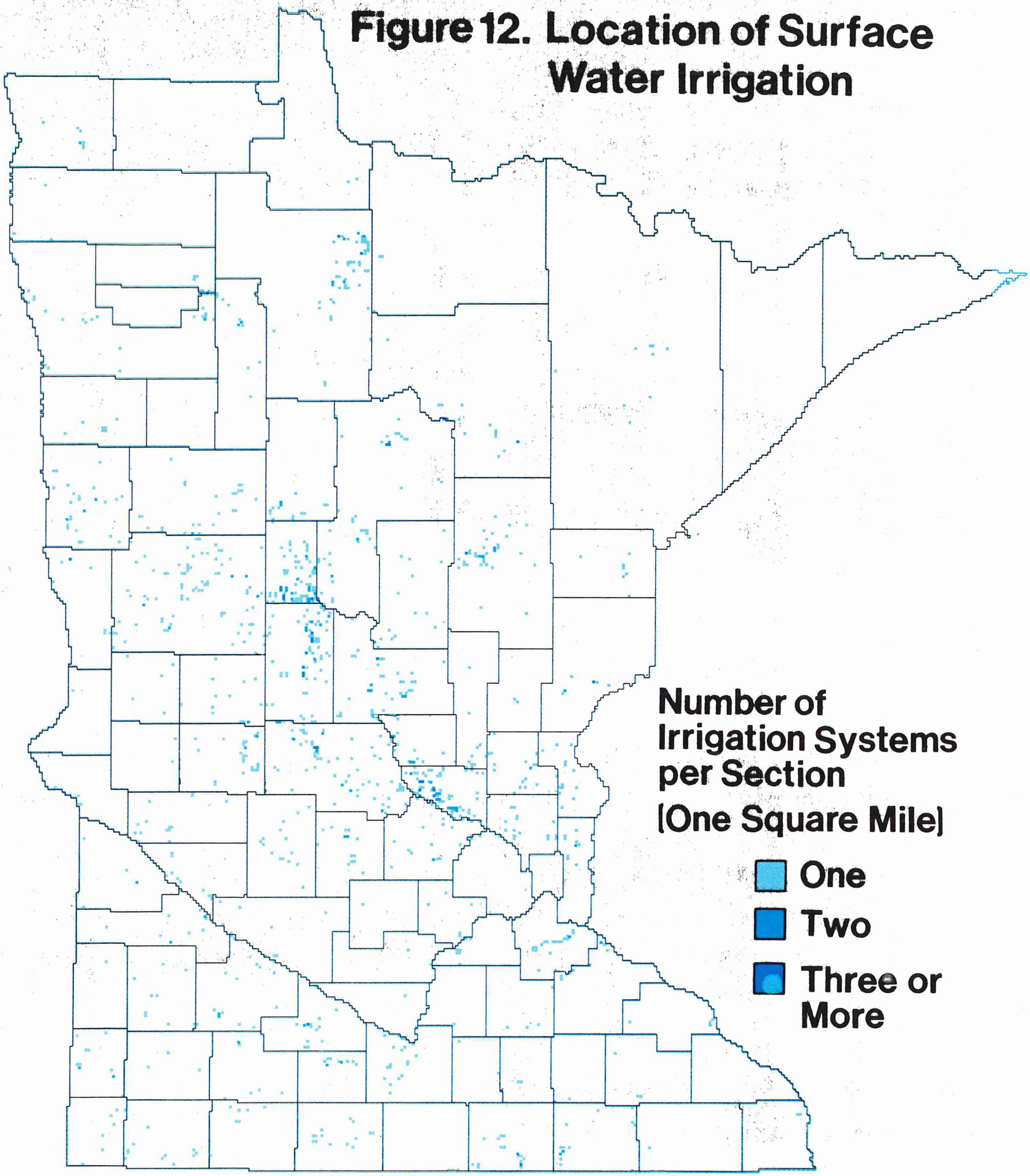
Rivers and ditches supply almost all of the water used for the irrigation of wild rice, which makes up 45% of all surface water irrigation acreage. Most wild rice is grown in Clearwater, Aitkin, and Beltrami counties, in areas which are generally classified as least suitable for irrigation of most agricultural crops.

Use of Ground Water for Irrigation

Ground water is available across Minnesota from a wide variety of sources. Glacial outwash and alluvial sand and gravel deposits are the most easily developed and most widely used source for irrigation systems. Paleozoic bedrock formations in the southeastern part of the state are more commonly used for municipal supplies. The major limitations in developing a ground water irrigation source are the potential for insufficient yield (controlled by local geology) and the high cost of drilling.

Ground water is stored in the pore spaces and fractures of rocks and sediments. An aquifer is defined as a geologic formation capable of yielding water to wells. The amount of water which can be pumped from a well will depend on the amount of water stored in these spaces, the ability of the aquifer to transmit the water, and the areal extent and thickness of the formation.

Figure 12. Location of Surface Water Irrigation



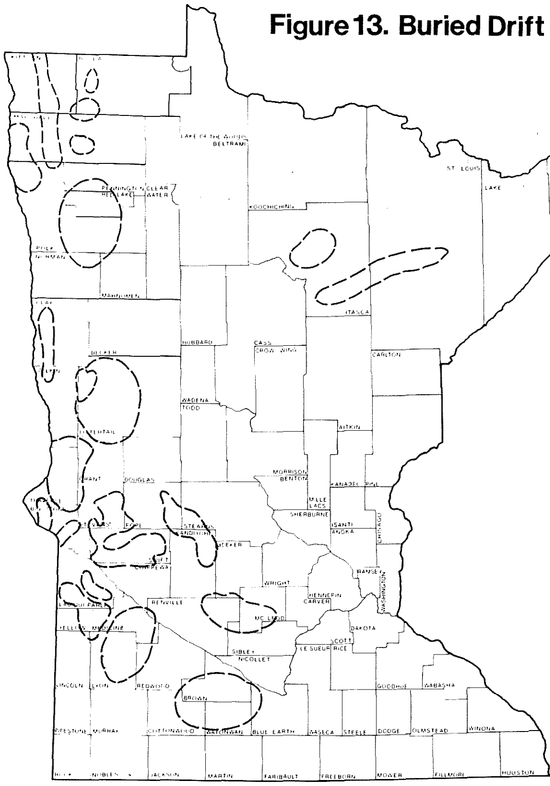


Figure 13. Buried Drift Aquifers

Unconsolidated Aquifers

Glacial deposits of sand and gravel typically are very good water sources. These unconsolidated aquifers may be covered by a confining layer (buried) or unconfined (surficial). Both buried and surficial aquifers in the state have been mapped (Figures 13 and 14). Although surficial sources cover approximately one third of state, those which can supply the high rates of pumping needed for irrigation are considerably less extensive. For example, in areas of the eastern portion of the vast Anoka Sand Plain north of the Twin Cities, the outwash is too thin to maintain high water yields.

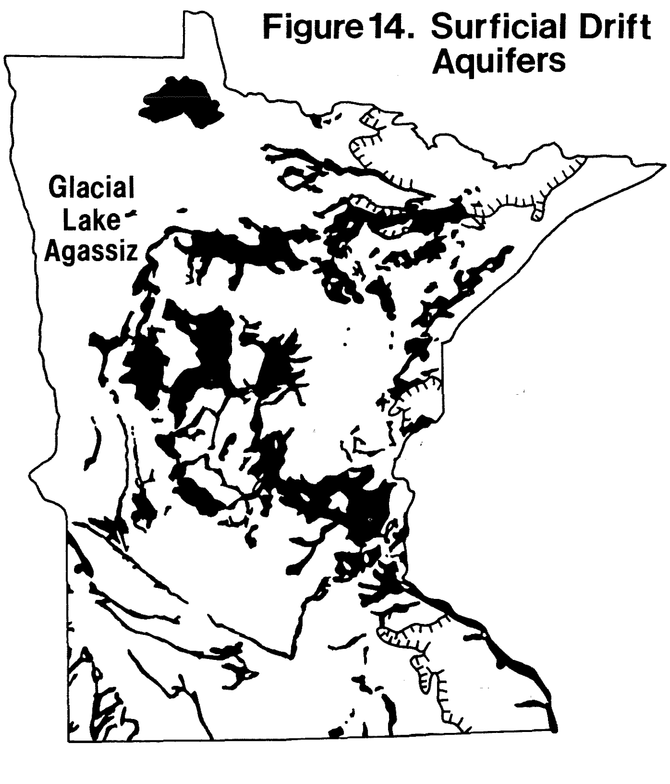


Figure 14. Surficial Drift Aquifers

Figure 15 shows areas where yields of 500 gallons per minute or greater are likely to be found. Sources yielding water of unsuitable quality for irrigation were omitted. Theoretical and estimated well yields were obtained primarily from USGS Water-Resource Investigations, Water-Supply Papers, and the Hydrologic Atlas Series. Additional information was taken from Water Well Records and DNR permit data.

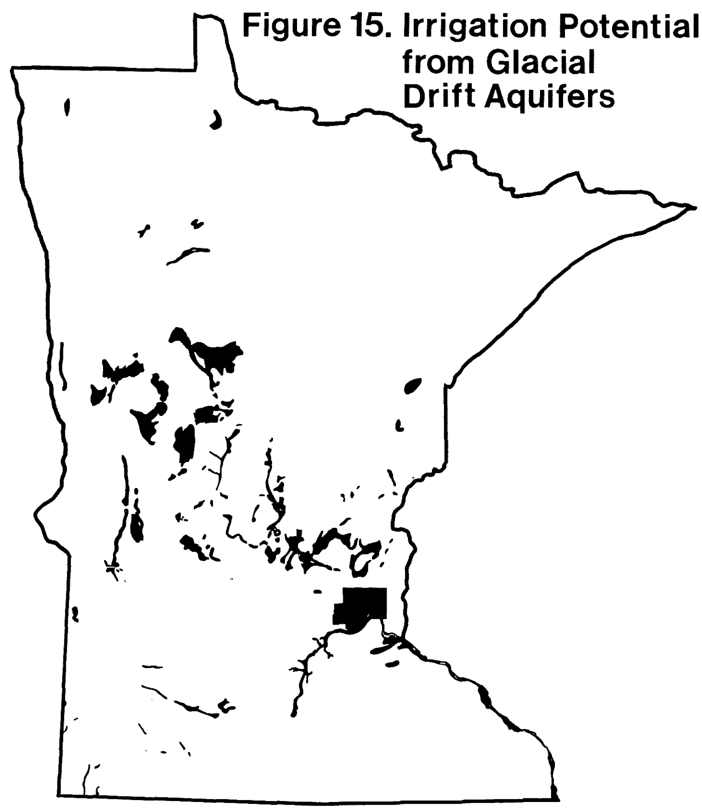
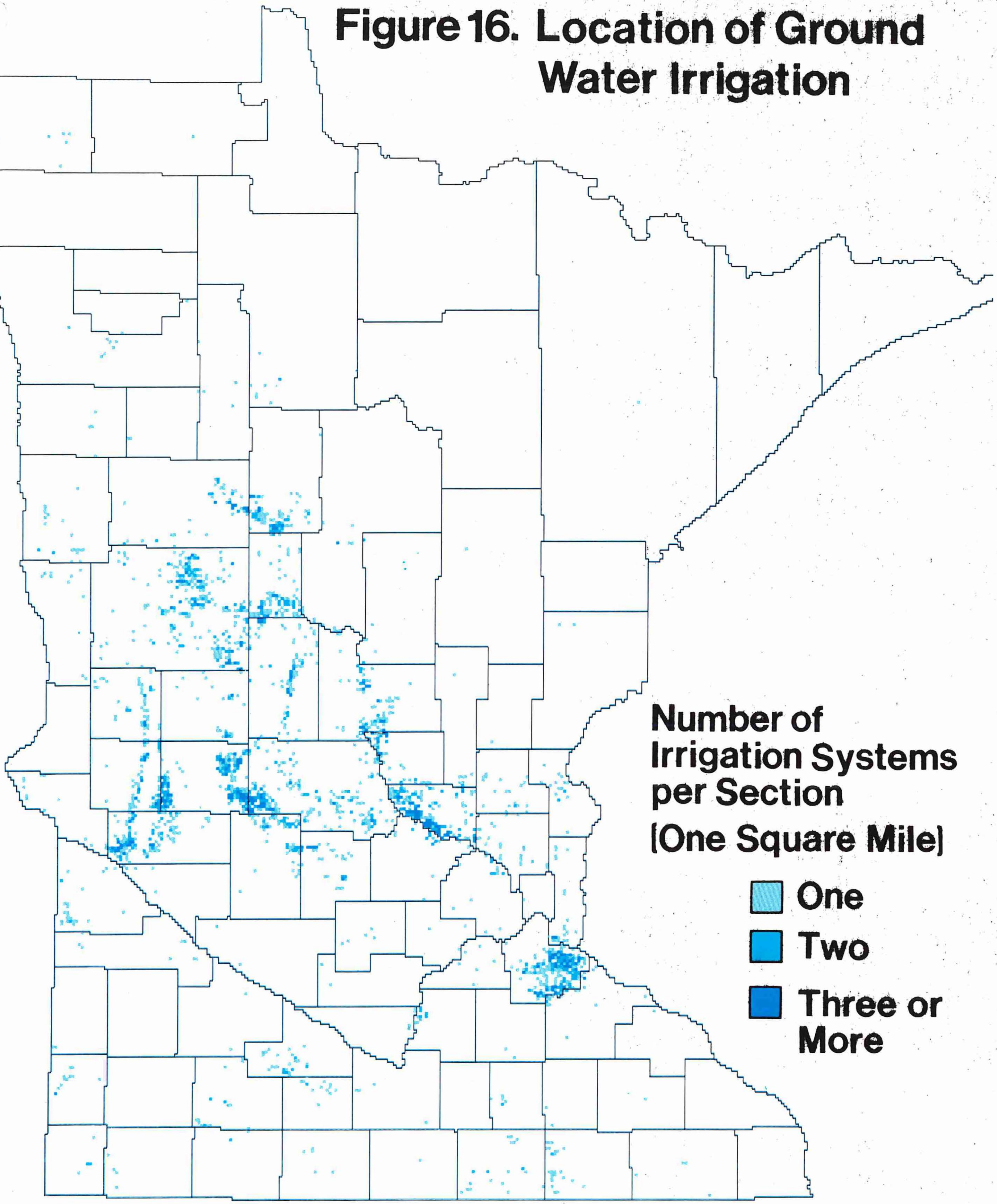


Figure 15. Irrigation Potential from Glacial Drift Aquifers

Figure 15 is not meant to indicate whether irrigation is feasible at any given location. Instead, it is intended to provide a regional assessment of potential irrigation water supplies. It also provides a basis for understanding the extent to which these areas have been developed.

Figure 16. Location of Ground Water Irrigation



The majority of existing irrigation occurs within the surficial outwash sand and gravel aquifers (Figure 16). The soils which form from these coarse-grained materials are limited by their poor water retention characteristics and are of marginal agricultural value without irrigation. The high permeability of the outwash deposits, however, makes these same areas excellent sources of water when there is 30 to 40 or more feet of saturated thickness.

In addition to outwash, alluvium (sediment deposited in river floodplains) has been developed extensively along the Pomme de Terre and Chippewa Rivers in Grant, Stevens, Pope, and Swift counties. Other alluvial sediments along the Mississippi River floodplain also supply irrigation wells. Of less importance is the alluvium which occurs along the many streams across all of southern Minnesota. These deposits are of small areal extent, generally too thin to support high capacity wells, and are regionally insignificant as sources.

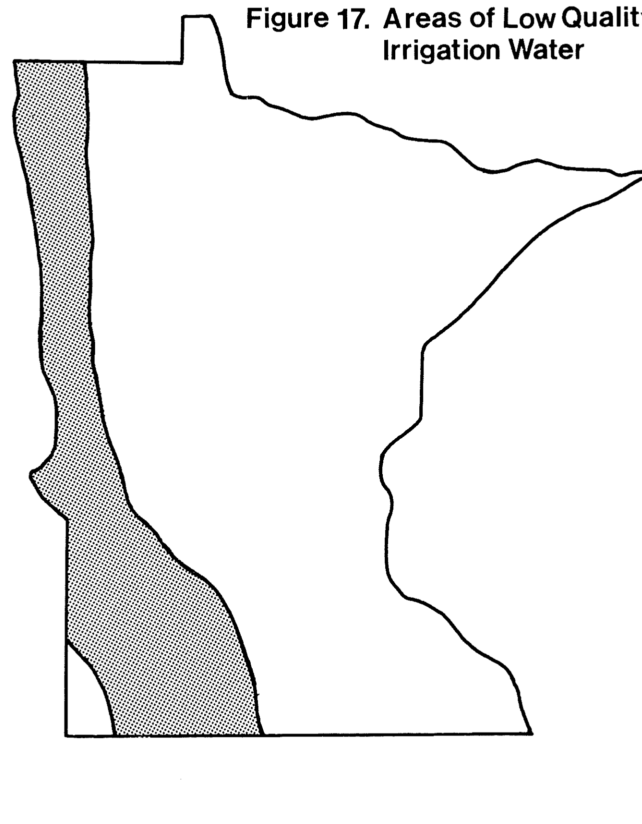
Beach ridge deposits of sand and gravel along the shores of glacial Lake Agassiz in Polk, Norman, and Clay counties are also used as sources. The amount of water these aquifers can deliver is limited by their small areal extent and their tendency to go dry in late summer.

Buried deposits of sand and gravel are another source of water in unconsolidated glacial drift. Information on these sources is not widely available and further study is necessary before accurate assessments of yields are available. Irrigation permits have been issued for water withdrawn from buried sands in Lac Qui Parle, Pope, Stearns, and Kandiyohi counties and were included on Figure 15 after examination of well logs in and around the area.

Smaller buried glacial drift aquifers can be present anywhere in the state except where glacial deposits are absent. Considerable test drilling is recommended to locate these lenses which are generally not extensive or interconnected. The till deposits which surround buried lenses of sand and gravel are generally impermeable, and are at best capable of supplying small water users such as stock tanks and domestic systems. Glacial drift is thickest over bedrock lows and thinnest over bedrock highs. The thicker the drift, the better the odds of intercepting a sand or gravel bed. Deposits vary vertically and areally and development is risky. Even though a lens may be thi and have a high initial yield, the relatively l water yielding potential of the overlying till may prevent sufficient recharge to sustain withdrawal, especially from several appropriators.

Water quality of buried sands may be less suitable for irrigation for several reasons. Compared to water in surficial aquifers, water in buried drift aquifers has a longer retention time in the subsurface. As a result of longer contact with the mineral grains, the water has higher concentrations of dissolved constituents. Water quality in buried lenses may be degraded from poor water quality in the bedrock below. An example is along the western edge of the state where poor quality (salty) water from Cretaceous sediments has migrated upward into overlying buried drift aquifers, resulting in high concentrations of dissolved solids (Figure 17).

Figure 17. Areas of Low Quality Irrigation Water



Bedrock Aquifers

Underneath the glacial drift is the bedrock. The adequacy of glacial deposits as sources in most parts of the state generally precludes development of bedrock aquifers for irrigation purposes. High drilling costs and uncertain yields also serve to discourage potential irrigators.

Bedrock aquifers have not been used much relative to other potential sources, except in the southeastern part of the state. Suitable sources are found in sedimentary rocks in southeastern Minnesota in the Hollandale embayment and in the Mesabi Iron Range in northern portions of the state. Elsewhere in the state, low yields and poor quality water prevent the development of sources.

Crystalline rocks underlie the entire state and are generally considered relatively insignificant sources of water. Low yields are possible but are dependent upon intercepting fractures within the rock. The size and degree to which these fractures are interconnected will determine how much water can be obtained.

The Cretaceous aquifer which directly underlies drift in the southwestern portion and along the eastern margin of the state contains water which is unsuitable for irrigation. Poor quality water, locally high in dissolved solids and boron, make the occasional sandstone lenses undesirable irrigation sources. In the northwest corner of the state, the Red River-Winnipeg aquifer may yield sufficient quantities but the water is briny and unsuitable for irrigation.

Water from buried drift aquifers lying above the Red River-Winnipeg and Cretaceous aquifers may be unsuitable for irrigation due to vertical migration of solutes into the drift.

Figure 18 shows the approximate outline of the Hollandale embayment in southwest Minnesota. Sandstones, dolomites, and limestones of Paleozoic age and Precambrian sandstone and conglomerates are excellent sources of water. The high permeability of these rocks relative to shale, quartzite, and dense crystalline rocks make them suitable sources.

The carbonate rocks above the Decorah shale (the Upper Carbonate aquifer) can produce sufficient yields when solution channels and fissures are intersected in the areas where karst topography is developed.

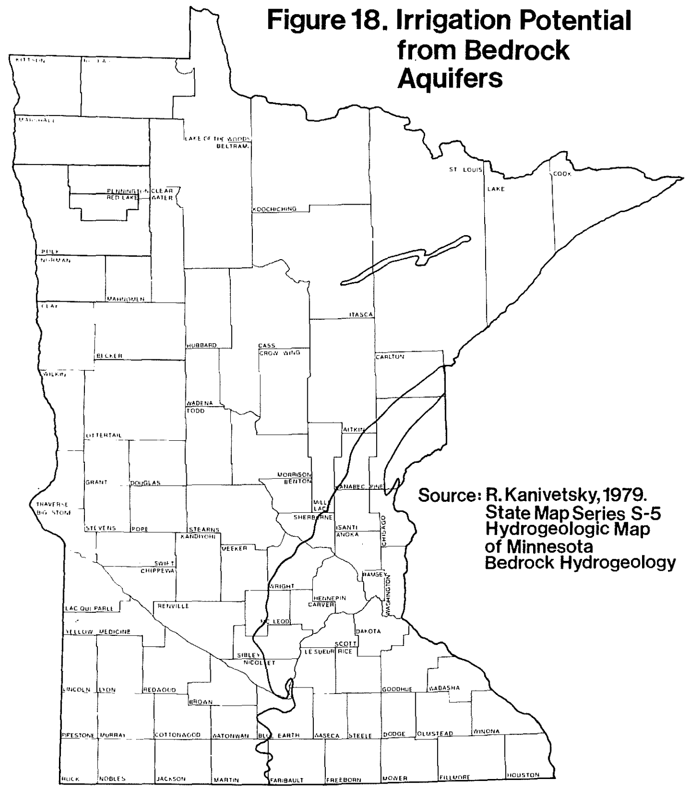


Figure 18. Irrigation Potential from Bedrock Aquifers

Source: R. Kanivetsky, 1979. State Map Series S-5 Hydrogeologic Map of Minnesota Bedrock Hydrogeology

Perhaps the best bedrock source of irrigation water is the Prairie du Chien-Jordan aquifer. This aquifer has been extensively developed and is used to irrigate much of the coarse outwash soils in Dakota County. Both units are capable of supplying over 1,000 gpm to wells and thus are favored by irrigators.

The Franconia-Ironton-Galesville and the older Mt. Simon-Hinckley aquifer units are the deepest sedimentary bedrock aquifers in the Hollandale embayment. The younger aquifer units above these formations make development unnecessary except outside of the boundaries of the Prairie du Chien-Jordan aquifer.

ECONOMICS OF IRRIGATION

Water resource managers must anticipate future demands for water in order to identify and minimize areas of potential water conflicts. For irrigation, this implies that they try to foresee when and where new irrigation systems will be installed in the state, and develop plans for managing the water resources accordingly. The previous section of this report described where irrigation might take place. This section will attempt to determine when irrigation might take place in the state.

For a farmer, the decision to install an irrigation system ultimately becomes a question of economics. He will irrigate only if he believes that doing so will increase his income. The final decision will be based on a careful analysis of the costs of an irrigation system and the benefits he expects to receive, considering both annual cash flows and long-term profitability.

Although economic conditions, land, and access to water may vary widely, we can assume that as crop prices rise or costs of production fall, then more farmers will find it profitable to irrigate. Similarly, if crop prices fall or production costs increase, fewer farmers will purchase irrigation equipment. The evidence over the last ten years suggests that these assumptions are true, at least with regard to crop prices. During the mid 1970's, prices were rising and so was the number of new irrigation systems. Since 1983, prices have fallen, and few additional acres of land are being irrigated.

It is difficult to assess the significance of these conclusions, however, because the price increases were also accompanied by a fairly severe drought, and the price decreases came during years of above normal precipitation. It could be argued that these climatic events had as great or greater impact on the purchase of irrigation equipment as price changes. Since economic changes are as difficult to predict as climatic changes, any speculation regarding trends in irrigation usage seems unwarranted. Therefore, this report will not attempt to predict changes in the use of irrigation for any specific time frame. We will, however, discuss some of the factors involved in making the economic decision whether to irrigate, and let the reader draw whatever conclusions he or she wishes to make regarding the next drought or grain deal with the Soviet Union.

A prospective irrigator has two economic concerns when making a decision regarding a r[illegible] irrigation system. First, net return over the lif[illegible] [illegible] the system must be positive. Second, annual income must exceed annual costs, or some other source of funds must be available in order to meet expenses. It is possible that an irrigation system will be profitable in the long term, yet during the first few years loan payments and operating costs will be greater than the income received from the sale of the crops. This may be especially true for first-time irrigators, who require a few years of experience before they can attain the highest potential yields from their system.

The main variables in the design of an irrigation system are the source of water, the source of power, and the type of distribution system. In Minnesota, the most common power sources are electricity and diesel fuel, and the most common distribution system is the center pivot. Table 6 shows a cost comparison for five different water sources. These costs are based on estimates from west central Minnesota in 1982.

Fixed and operating costs will also va[illegible] depending on the crop being irrigated. Tabl[illegible] shows a sample comparison of operating costs for the production of four commonly irrigated crops. Yield goals are based on the application rates for planting, fertilizer, pest controls and irrigation.

Other factors may influence the decision to install irrigation equipment. While they may not appear on the balance sheet, these factors can have significant impacts on the profitability of the farm. Among the side benefits of irrigation may be a reduction of the variability of net returns (a more stable income). Irrigation may ensure a supply of feed for on-farm livestock. It may increase after-tax income through investment tax credits and rapid depreciation. It may also expand the number of options available for what might otherwise be marginal land. For some farmers, irrigation may not be a viable alternative due to a lack of adequate water, credit, or labor and management time.

Table 6: A Cost Comparison of Alternative Irrigation Water Supply Systems for 130-acre Center Pivot System.

Water Supply	Well	Well	Well	Well	Surface
Supply Size	1-12"x35'	3-12"x35'	1-12"x70'	1-12"x210'	lake
Pump Lift	25'	25'	50'	100'	20'
Pump Type	Turbine	Submersible	Turbine	Turbine	Centrifugal
Brake HP	26	39	44	58	35
Initial Investment					
Water Supply	$4,900	$14,000	$8,400	$18,200	----
Pump Unit	$4,000	$10,500	$4,500	$5,500	$3,100
Power Unit	$4,900	----	$5,200	$6,700	$4,900
Pipeline	$2,000	$2,000	$2,000	$2,000	$2,000
Center Pivot	$32,000	$32,000	$32,000	$32,000	$32,000
Accessories	$2,000	$2,000	$2,000	$2,000	$2,000
Total	$49,800	$60,500	$54,100	$66,400	$44,000
(per acre)	($383)	($465)	($416)	($511)	($338)
Annual Ownership Cost					
Depreciation	$3,271	$3,833	$3,500	$4,157	$2,967
Interest	3,136	3,812	3,410	4,182	2,772
Insurance	214	222	225	225	210
Total	$6,621	$7,867	$7,135	$8,564	$5,949
(% of initial investment)	(13.3)	(13.0)	(13.2)	(12.9)	(13.5)
Annual Operating Cost (10 inches of water)					
Energy and Lubrication	$1,860	$2,020	$2,200	$2,840	$1,830
Maintenance	$220	$250	$230	$260	$200
Total	$2,080	$2,270	$2,430	$3,110	$2,030
(per acre-inch)	($1.60)	($1.75)	($1.87)	($2.38)	($1.56)
Labor	$490	$525	$490	$490	$560
Annual Cost per Acre Irrigated (10 inches)					
Ownership	$50.93	$60.52	$54.88	$65.88	$45.76
Operating	$16.00	$17.46	$18.69	$23.85	$15.62
Labor	$3.77	$4.04	$3.77	$3.77	$4.31
TOTAL	$70.70	$82.02	$77.34	$93.50	$65.69

***Assumptions:** Low pressure electric 20 psi spray center pivot; electric powered pumping motor; brake horsepower equals pump plus center pivot requirements. Accessories include a water meter and chemical injection unit. Annual ownership costs are calculated on a straightline depreciation with no salvage value for 20 years on the well and pipe; 15 years on pump, power, and sprinkler unit; and 10 years on all other components. The interest rate is 14%. Insurance is 0.5% of the investment price for all components except the well and buried pipe. Operating costs for the electric pump are fixed charges of $300.00, demand charge of $6.50 per kilowatt per month for four months and an energy charge of $0.04 per kilowatt-hour.

The greatest unknown for any prospective irrigator is the price he will receive for his crops. Over the last ten years, corn prices peaked at about $3.23 (Minnesota Department of Agriculture, 1986) per bushel in the summer of 1984, and in the spring of 1987 are around $1.70 per bushel (Star and Tribune, 1987). Uncertainty regarding crop prices is probably sufficient in itself to prevent most farmers from purchasing an irrigation system. It is doubtful whether they could show a profit at $1.70 per bushel, but they probably

Table 7: Irrigated Crop Production Budget.

	Field Corn	Soy-beans	Navy Beans	Table-stock Potatoes
Planting	$40	$26	$40	$233
Fertilizer	$33	$12	$17	$60
Pest Control	$34	$27	$31	$51
Irrigation	$22	$16	$13	$25
Harvest	$103	$28	$25	$125
Overhead	$107	$95	$101	$160
TOTAL	$339	$204	$227	$654
Yield Goal	150 bu.	45 bu.	20 cwt.	250 cwt.
Break Even Price	$2.26	$4.54	$11.35	$2.62

Source: Jerry Wright, University of Minnesota Extension Service

could at $3.23. The authors decline to speculate at any price in between.

One way to improve our understanding of the economics of irrigation is to take a closer look at those farmers who have installed irrigation systems over the last five years. Given the downturn in crop prices, the surplus of moisture, and the difficulty in obtaining credit, farmers who purchase irrigation equipment in the late 1980's must be fairly confident that irrigation will provide a net economic benefit to their operation. In order to identify any trends in the installation of new systems, we chose to compare new irrigators to farmers who were expanding their existing irrigated acreage. Presumably, if an irrigator decides to expand acreage, past experience has shown that such a move would be profitable. Thus, we might assume that irrigation could have a net economic benefit for other farmers should they decide to irrigate.

Table 8: Increase in Irrigated Acreage 1982 - 1986.

	First Time Irrigators	Existing Irrigators	Total
Number of Permits	229 (52%)	208 (48%)	437
Acres Irrigated	19,388 (46%)	23,105 (54%)	42,493
Average Acres Per Permit	85	111	100

From Table 8, approximately one-half of all new irrigation systems were installed by farmers who were already irrigating cropland in 1982. Irrigators, who represent a very small portion of all farmers in the state, are apparently more willing to add new irrigated acreage than non-irrigators. Some caution must be observed before inferring too much from these statistics. There is a learning process which must be completed when farmers first irrigate; experienced irrigators are more likely to be able to turn a profit sooner. Experienced irrigators may be in a better financial condition than non-irrigators and can more readily obtain credit. The fact that an irrigator is adding acreage implies that he is a large landowner, or is able to lease larger amounts of property. No attempt was made to compare large versus small farms in this analysis. Perhaps only larger operations are able to afford or profit from irrigation. Nevertheless, expansion by existing irrigators may be an indication that irrigation continues to be profitable in Minnesota, even during periods with low crop prices.

IMPACTS OF IRRIGATION ON THE ECONOMY

The use of irrigation has economic impacts which go beyond the individual farmer. The purchases made by an irrigator are different from those of other farmers. In areas where irrigation is prevalent, the combined effect of these purchases can have a significant impact on the local economy. A typical irrigator purchases more agricultural services and electricity than a typical dryland farmer and buys more products from outside the local economy. On a percentage basis, an irrigator spends less for household items and saves less of his total income (Maxwell and Dorf, 1982).

The higher yields produced on irrigated land generate additional income for the farmer. A study of farms in Swift County, Minnesota, found that the average gross income from an acre of irrigated land was $338 in 1980, while an acre of non-irrigated cropland yielded $125. The additional $213 income from irrigated land is then used to purchase goods and services. These purchases provide income to local merchants, who in turn use this cash to buy goods and services for their own use. In this way the original income of the farmer is multiplied as it passes through the local community. The combined impact of these secondary purchases was estimated to be $235. Thus, an average acre of irrigated land generates an additional $448 in direct and indirect sales for the local economy (Maxwell and Dorf, 1982).

The use of irrigation can have an even larger impact on the economy during a drought year. Although production of dryland crops on sandy soils is drastically reduced in a drought, irrigated lands should achieve fairly normal yields. For a rural, farm-based community, the more stable income resulting from consistent yields on irrigated lands can lessen the economic impact of the decline in purchasing power of dryland farmers (Maxwell and Dorf, 1982).

Although the scope of this study was limited to Swift County, its conclusions should be valid for any area where irrigation is practiced. However, the magnitude of the impacts of irrigation may vary. Most irrigation in Swift County takes place on sandy soils. As we have seen, the greatest benefits from irrigation are achieved on the these soils. Therefore smaller impacts can be expected on the finer soils found elsewhere in Minnesota.

AGRICULTURAL PROCESSING

Water for agricultural processing is as important to Minnesota as water for irrigation. The production of food only starts with the harvest. Corn and soybeans are fed to cattle, hogs, and chickens. These animals are then butchered for meat. Wheat is milled into flour and flour is kneaded into bread dough. Vegetables are canned, frozen, stewed, creamed, and pureed. These steps are necessary before food can be brought to the table, and they all require water for cleaning, cooling, heating, mixing, carrying, and drinking. Processing plants cannot depend on rainfall.

The major water users for agricultural processing are dairy, beverage, meat and sausage, poultry, and vegetable processing. While grain milling, bakery products, and fat and oil producers are significant agricultural processing sectors in Minnesota, their water use is considerably lower. These industries are primarily very small firms, most employing fewer than eight people (Directory of Manufacturers, 1986). Since their water use is relatively small and difficult to estimate, this report will not discuss these minor water users. Despite its small water requirements, the sugar beet processing industry will be discussed because it is an example of the ways in which industrial water needs can change.

ESTIMATING WATER USE

It was necessary to utilize several direct and indirect sources of information to obtain a complete picture of agricultural processing water use in the state. Many larger processing plants have water appropriation permits; the volumes of water they pump are reported annually to the DNR. However, the information provided by the annual reports was insufficient for this analysis. More complete data were obtained through a survey of all non-irrigation appropriation permit holders. The survey attempted to determine more precisely the ways in which water was used at each plant, and what products were actually processed or manufactured. Permit holders were also asked to estimate the percent of the total water withdrawn by their operations which was consumed (that is, not returned to a stream or other water source) and whether they purchased any water from a municipality. Often a processing plant with access to its own water source will use a municipal supply system as a backup and as a source of drinking water for its employees.

Many agricultural processors in the state use municipal supplies as their sole source of water, since most municipalities provide a stable supply of high quality water at low cost. In order to identify these secondary water users, all municipal water utilities were surveyed. The utilities were asked to list their larger industrial water users and the average volumes used each year. Contacting the municipalities rather than the end users greatly facilitated the survey; addresses of the water utilities were known from their water appropriation permits, and fewer contacts were necessary because most utilities serve more than one industrial user.

The agricultural processors who do not have appropriation permits and who were not included in any survey were identified through the *1985/1986 Minnesota Directory of Manufacturers*. Water use was then calculated based on average water use per employee for each category of agricultural processing. These averages were derived from the quantities of water used by permitted and surveyed processors and their respective employment data taken from the Directory of Manufacturers. The results are shown in Table 9.

Table 9: Average Water Use Per Employee Selected Industries.

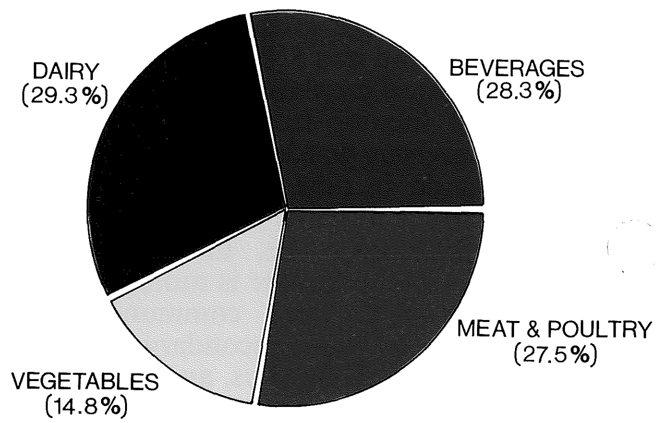
Industry	Water Use/Employee (gallons/year)
Meat and Sausage	200,000
Poultry	395,000
Dairy*	620,000
Vegetables	356,000
Sugar Beets	209,000
Beverages:	
Non-alcoholic	130,000
Malt	3,490,000

* *Volume per employee increases with size of plant. Figure shown is overall average.*

WATER USE BY SECTOR

The five major water users among agricultural processors withdrew sixteen billion gallons (50,000 acre-feet) of water in 1985. As Figure 19 shows, the dairy, beverage, and meat and poultry industries each withdrew about 4.5 billion gallons, while vegetable processing used about one-half that amount. There are some significant differences among these industries in both the ways in which water is used and the locations of their major plants.

Figure 19. Water Use in Selected Agricultural Sectors
1985
TOTAL 16,083 MILLION GALLONS



Dairy

Minnesota is a major source of dairy products for the nation. The state ranks fourth in the production of milk, second in cheese, third in butter, second in non-fat dry milk, and seventh in ice cream (Minnesota Department of Agriculture, 1986). While dairy processing employment has remained fairly constant over the last ten years, the number of plants has been reduced dramatically, from 284 in 1975 (Minnesota Department of Agriculture, 1977) to 112 in 1985, (Nelson Marketing Services, 1986) as many smaller plants closed and larger operations expanded.

Processing facilities use water in a variety of ways: for cooling and condensing of dairy products, for the cleaning of equipment and tanker trucks, and for boiler makeup water. "Cow water," which is the condensate of evaporated or dry milk production, is often recycled within the plant for boiler feed or cleaning.

Dairy processing plants are concentrated in the southern half of the state, with a number of plants in or near the Twin Cities metropolitan area (Figure 20).

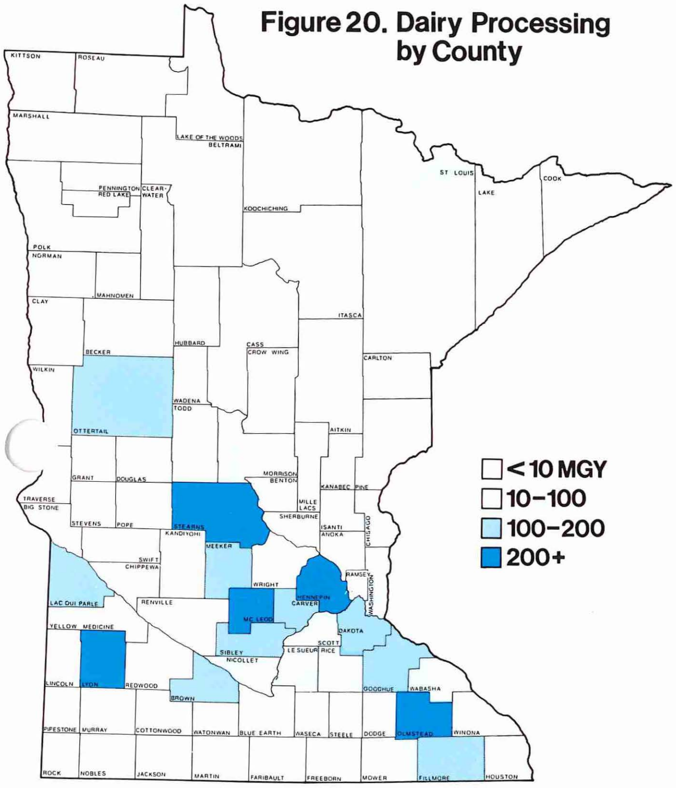


Figure 20. Dairy Processing by County

Beverages

The production of beverages may be considered a secondary step in agricultural processing, but it is included here because it constitutes a major portion of the water used for food production in the state. Minnesota beverage producers include four major breweries, two wineries, one distillery, and forty-four soft drink plants (Figure 21). Related facilities also included are eight malting companies and seven producers of flavoring extracts and syrups.

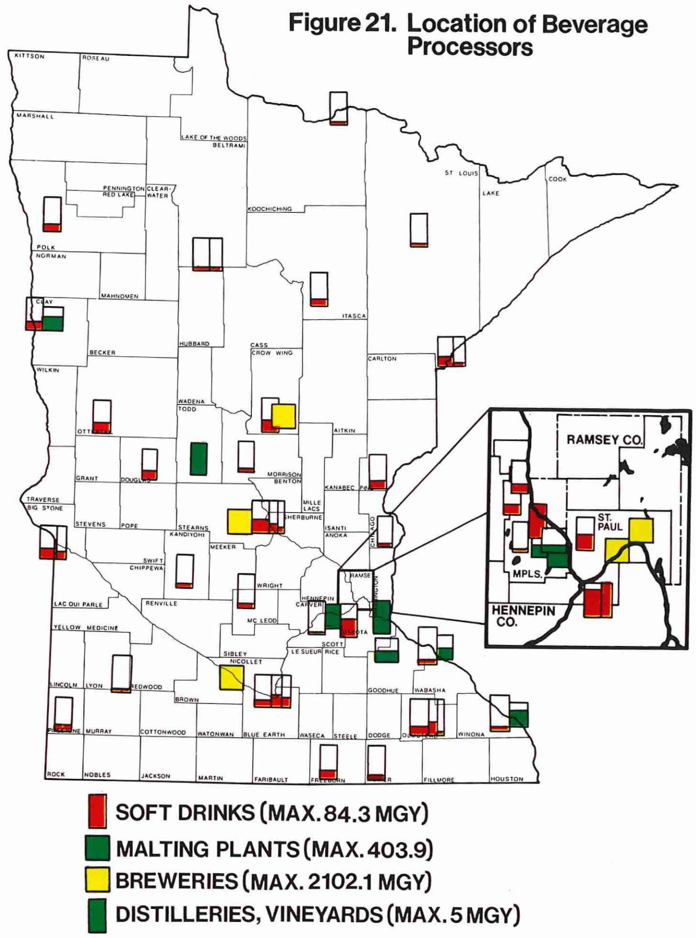


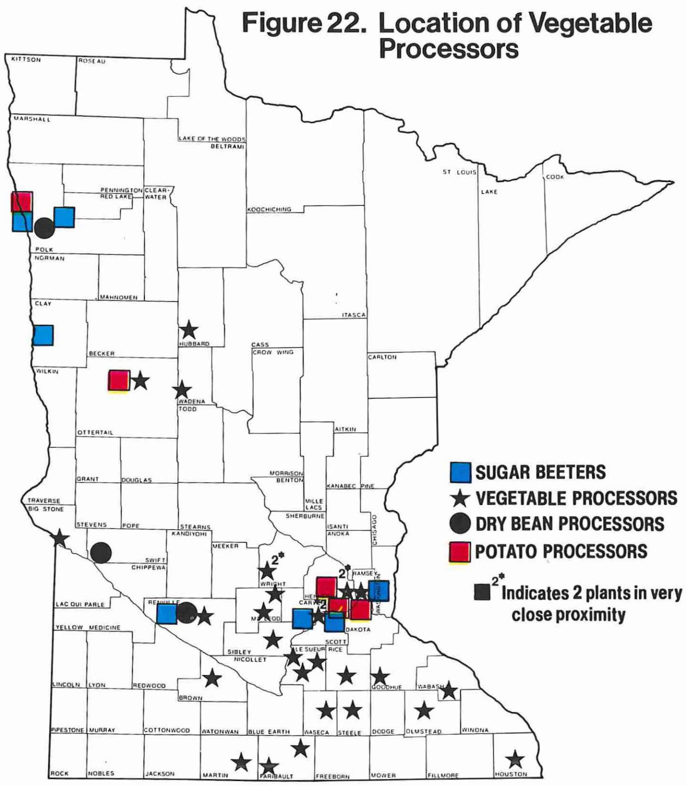
Figure 21. Location of Beverage Processors

Water is obviously a necessary ingredient for processing these products. It is also required for cooling, cleaning, and boiler makeup. Non-alcoholic beverage plants tend to be located in larger cities and use municipal water supplies instead of drilling their own wells. Breweries and malting plants prefer to have their own source of "naturally pure spring water," which usually means a deep well.

Vegetables

The Minnesota River Valley is a major production area for several national brands of vegetable processors. Minnesota produces more sweet corn for processing than any other state and ranks second in the production of green peas. (Minnesota Department of Agriculture, 1986). Potatoes and pickles are also important agricultural products (Figure 22).

Figure 22. Location of Vegetable Processors



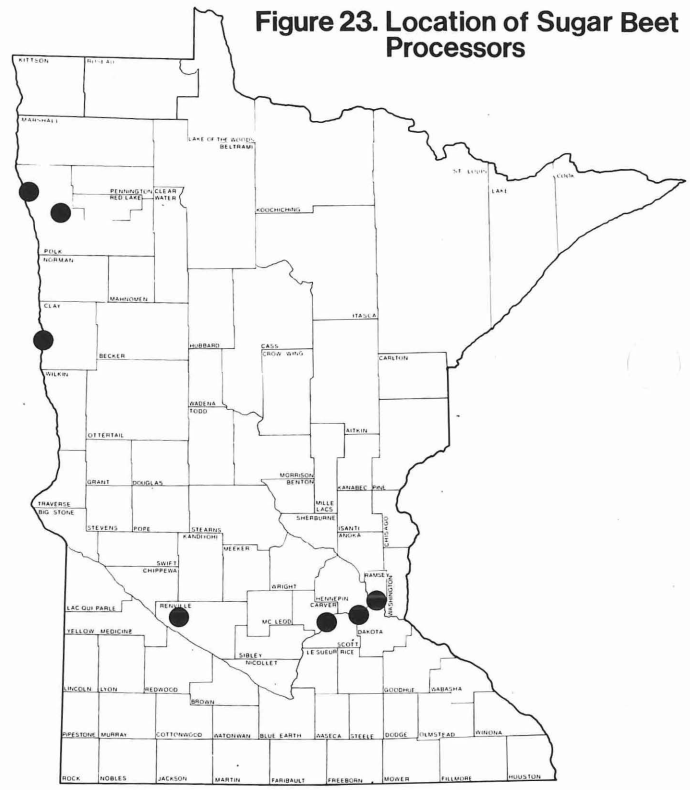
Some processing plants have the capacity to can both peas and corn. Peas are usually packed between mid-June and mid to late July. The corn season then starts in mid-August and goes until mid or late September. The plants are shut down between runs for cleaning and changing of equipment (Minnesota Department of Agriculture, 1977).

For most products, plant operations are seasonal, and so are water demands. Water is used for transporting and cleaning vegetables, cooling sealed containers, cleaning of equipment, and boiler makeup. Some water is used directly in processing, either pure or as brine. Most canning operations reuse wastewater by irrigating nearby cropland. In 1985, an estimated 2,080 acre-feet of water were reused in this manner by sixteen canneries (Trotta, 1986).

Sugar Beets

Minnesota farmers harvested 5.1 million tons of sugar beets in 1985, almost 14 percent more than the average harvest between 1977 and 1985. The number of acres in sugar beet production has climbed steadily over the last four years, as government supports have maintained prices well above the world market (Minnesota Department of Agriculture, 1986). At the same time, the amount of water used for sugar beet processing has declined dramatically. Water use at the five major processing plants in Minnesota has dropped from 3094 acre feet in 1973 to 806 acre feet in 1985 (Figure 23).

Figure 23. Location of Sugar Beet Processors



A change in processing methods was primarily responsible for the decrease in water use at these plants. Largely because of environmental concerns, the sugar beet industry has gone from using water on a "once-through" pass for cooling and washing to a closed loop system where water is recycled through the plant many times before it is finally treated and discharged. Extensive treatment, including the use of aerobic and anaerobic microorganisms, is required in order for the plant to be in compliance with their Minnesota Pollution Control Agency discharge permits (Heinbauch, 1987).

Water serves several purposes at a sugar beet processing plant. It is used to wash the beets, as an ingredient in processing, for boiler feed water, for non-contact cooling, and for sanitation and general cleanup. Typically water is pumped from a river into a holding pond where it becomes a readily available source to be recycled back and forth between the plant and the pond. Sugar beet processing is a seasonal activity, beginning in September and ending whenever the beets are gone, usually in March. Little or no water is pumped during the summer months, when other demands for water are highest. (Minnesota Department of Agriculture, 1977).

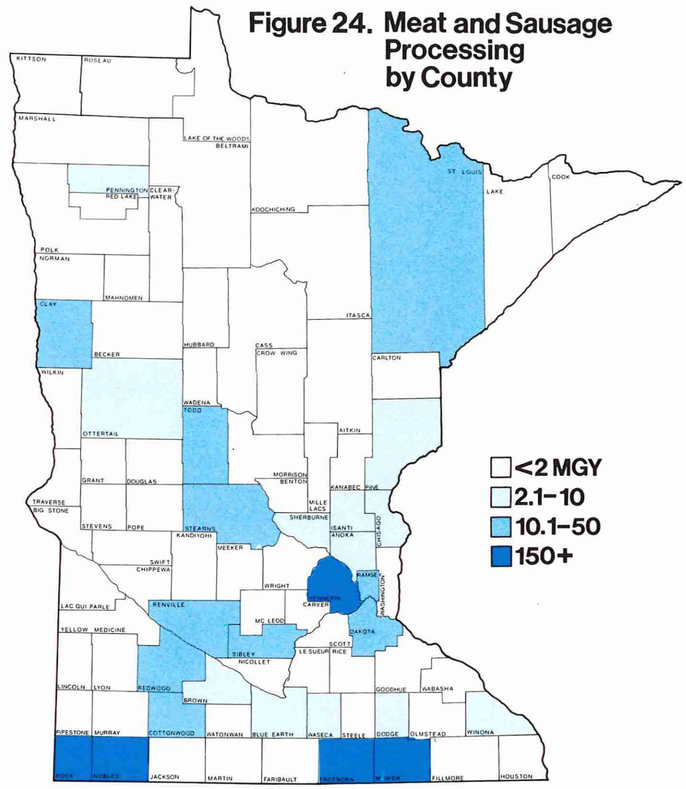
Meat and Sausage

Like the sugar beet industry, the demand for water in meat and sausage processing has declined over the last fifteen years. Unlike sugar beets, the demand has declined because of a decrease in meat and sausage production. Americans are eating less beef and pork than in the past. In fact, per capita beef consumption has dropped from 94.4 pounds per year in 1976 to 79.8 pounds in 1986. (Cohen, 1987). This reduction has led to the closing of many small packing plants and the consolidation of production at a few large plants. Another trend appears to be a movement by large corporations out of the upper Midwest and toward the major cattle producing regions of the central Great Plains (Stinchfield, 1987).

Meat packing industries require large volumes of water for animal slaughtering. Most of the water is used for cleaning carcasses, floors and walls, and livestock holding pens. Some water is used to feed livestock while they are in the holding pens. Processing facilities which do not slaughter animals, such as sausage plants, require much less water (Minnesota Department of Agriculture, 1977).

Large meat processing plants are concentrated near the Iowa border; virtually all of the plants are in the southern half of Minnesota (Figure 24). Since the plants operate year round, their demand for water is fairly constant from season to season.

Figure 24. Meat and Sausage Processing by County

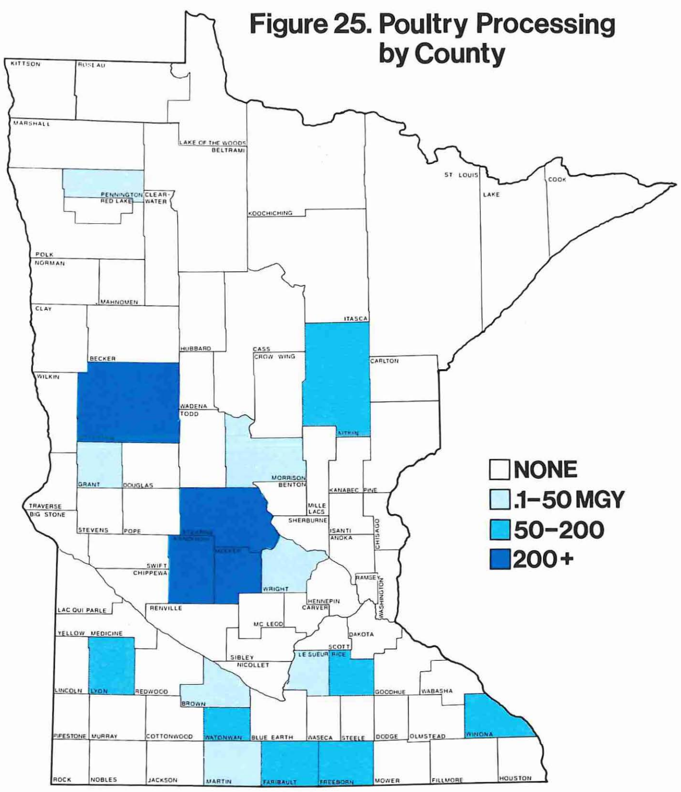


Poultry

Chicken and turkey production has seen a fairly steady increase over the last fifteen years. Minnesota ranks second in the nation in turkey production, behind North Carolina. (Minnesota Department of Agriculture, 1986).

Cleaning of poultry products and processing equipment requires a constant supply of water. Entire plants may be cleaned four times a day. Birds are scalded with water before processing to remove feathers and dirt. More water is used during slaughtering to remove feathers and entrails. Additional water is used for cooling of poultry products (Minnesota Department of Agriculture, 1977). While accurate data on the past use of water in the industry are not available, an increase in poultry production would imply a similar increase in the demand for water for processing (Figure 25).

Figure 25. Poultry Processing by County



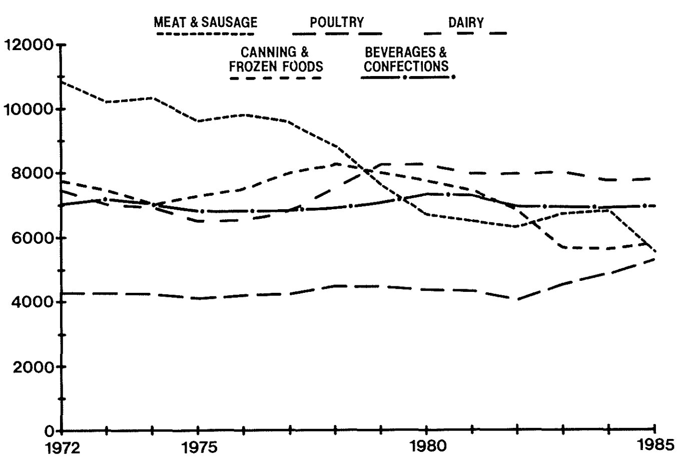
TRENDS IN WATER USE

No reliable data are available which show long-term trends in water use among agricultural processors. One way to estimate these trends is to look at known statistics regarding these industries and make assumptions based on available data. Employment figures offer such a potential. Statistics regarding employment are easily obtained and should be fair indicators of trends in water use, since a growing industry will probably require an increased amount of water in proportion to its increased employment and vice versa.

Figure 26 shows employment trends since 1972. These categories, from the Department of Jobs and Training, do not correspond exactly to our major water users. Canned and frozen foods include vegetables as well as jellies, sauces, fish, and pizza. Beverages and confections include confectionary items such as cookies and cakes, but not sugar beet processing.

Figure 26. Statewide Employment in Agricultural Processing

ANNUAL AVERAGES



The most significant change in agricultural processing employment over the last fifteen years has been the decline in the number of workers at meat and sausage plants. A smaller increase in employment in poultry processing partially offsets this change. Dairy, canning, and beverage and confections have exhibited minor fluctuations, with canning showing a net decline. Total employment for all sectors decreased from 37,375 workers in 1972 to 31,189 workers in 1985. (Wandersee, 1987). Based on this information, it is likely that water use for agricultural processing declined at a similar rate since 1972.

Estimating trends in water use solely on the basis of trends in employment ignores any other changes which may have taken place in these industries over the last fifteen years. As we have seen with the sugar beet industry, a change in manufacturing processes can greatly affect water withdrawal. It is likely that similar environmental concerns have caused changes in the other industrial sectors which would reduce water withdrawals. However, data which could substantiate this assumption were not available. Improved enforcement and data collection activities by the DNR will make this information available in the future.

LIVESTOCK PRODUCTION

The scale of livestock production in Minnesota ranges from a couple of horses in the back pasture to feedlots holding hundreds of cattle or hogs to chicken hatcheries housing hundreds of thousands of chicks. The primary use of water at these operations is for drinking, although some washing of animals and their quarters is required. While water use may be widely dispersed around the state, the total volume pumped each year is substantial. Since virtually all operations pump less than the minimum volumes required for a DNR appropriation permit, all water use data for livestock production must be estimated based on the number of animals of each type and an average volume of water consumed each day.

The United States Geological Survey has been estimating livestock water use in Minnesota since 1950. County livestock populations are taken from the Census of Agriculture and multiplied by standard consumption figures. Where county breakdowns are not available, estimates are made from statewide numbers. Average daily consumption rates are given in Table 10. It is assumed that 85 percent of all livestock water comes from wells, and 15 percent is taken from surface water sources. The exception is water for turkeys, which is assumed to be exclusively ground water (Trotta, 1987).

Large animals use more water than small animals, and lactating or egg-producing females use more than other animals of the same size. Cows consume about 75 percent of all water withdrawn for livestock; dairy cows alone account for almost one-half. Despite its minimal water requirements, the Minnesota mink industry is significant -- the state ranks second to Wisconsin in total production.

Much of the livestock production in the state is concentrated in a band which runs from Winona County in the southeast corner to Otter Tail County in west central Minnesota (Figure 27). Most beef cattle and hogs are raised in counties along the Iowa border. Stearns County, by far the leading dairy producer in the state, is also a major source of turkeys and chickens. Kandiyohi and Swift are major turkey-producing counties as well. Benton and Morrison Counties are also important chicken suppliers.

Figure 27. Livestock Water Use by County

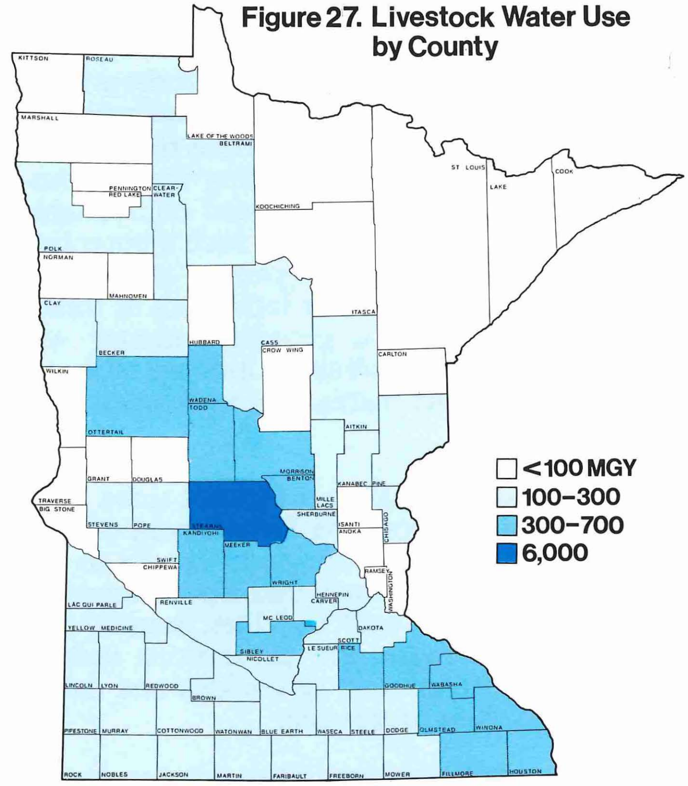


Table 10: Water Use for Livestock Species in Minnesota -1985.

Species	Estimated Use per Animal (gallons/day)	State Total (acre-feet)
Milk cows	18.4	32,900
Beef cows	8.7	4,100
Other cows	6.0	15,300
Hogs and pigs	2.6	11,500
Sheep and lambs	2.0	410
Horses, mules, etc.	12.0	730
Laying hens	0.061	630
Non-laying hens	0.039	75
Chicks	0.03	56
Broiler chickens	0.037	930
Turkeys	0.12	3700
Ducks, geese, etc.	0.04	10
Milk goats	6.0	20
Other goats	1.0	3
Mink	0.01	5
Rabbits, chinchilla	0.5	13
Total		70,300

Subtotals do not add to totals due to rounding.
Source: Trotta, 1987

The decline in water withdrawals shown in Table 11 probably reflects the decrease in the cattle population in the state. Although other animal populations increased during this time (Table 12), their consumption is small compared to that of cattle on a per-animal basis. Future trends in livestock water use will probably continue to follow changes in the diet of the American consumer.

Table 11: Trends in Livestock Water Use (acre-feet per year).

Year	Ground Water	Surface Water	Total
1950*	89,600	22,400	112,000
1955*	80,600	23,500	104,100
1960	61,600	17,900	79,500
1965	68,300	8,200	76,500
1970	66,100	10,100	76,200
1975	73,900	12,300	86,200
1980	65,000	11,200	76,200
1985	60,300	10,000	70,300

Includes rural domestic water use.
Source: U.S.G.S. Circulars 115, 398, 456, 556, 676, 765, 1007 and unpublished data for 1985.

Table 12: Trends in Livestock Populations (thousands).

	1976	1985
Cattle	4,430	3,550
Pigs and hogs	3,000	4,200
Sheep and lambs	315	255
Chickens	11,680	12,700
Commercial broiler chickens	15,200	26,900
Turkeys	24,370	30,400

All populations are on farms except broiler chickens and turkeys.
Source: Minnesota Department of Agriculture, 1981 and 1986.

WATER ISSUES AND AGRICULTURE

This report has focused on the ways in which water is used in the agricultural sectors of Minnesota. The volumes necessary for production have been described. Trends in use over time and the locations of major use within the state have been identified. If we turn the discussion around, however, we can examine the ways in which the use of water for agriculture affects the water resources of the state. Do we have enough water to meet all of our needs? How does the quality of the water we return to the stream or apply to our soil affect users down the road? These issues have been and will be important concerns for Minnesota.

IMPACTS ON WATER AVAILABILITY

When examining the impacts of water use on the total amount of water available from a certain resource, it is important to distinguish between the volumes of water withdrawn and the volumes which are consumed and are not returned to the source.

Irrigation is a consumptive use of water, since water is not returned to its original source and made available to another use. Similarly, almost all water used for livestock production is consumed, since its primary purpose is for drinking.

In contrast, much of the water withdrawn by agricultural processors is returned to a surface water source, such as a lake or stream. Typically, water is circulated through a coolant system, mixed with products or used for cleaning, and then treated and discharged. Only a portion of the water evaporates or is incorporated into the final product. The amount of water consumed varies with each industry (Table 13), but is usually less than one third.

Environmental regulations have encouraged processors to increase the amount of recycling and reuse of water in their plants. While this practice decreases the amount of withdrawals necessary for their operations, it also tends to increase the percent of water consumed. Each time water is circulated through the plant, more of it evaporates away or is incorporated into th final product. The net result is a decreas th amount of water discharged.

Table 13: Consumption of Water in Agricultural Processing.

Sector	Percent of Water Withdrawn Which is Consumed
Meat and Poultry	7.7
Dairy	7.5
Vegetable	11.5
Grain Milling	6.3
Bakery Products	33.3
Sugar and Confections	20.5
Fats and Oils	15.2
Beverages	22.9
Miscellaneous	18.7

Source: Water Use in Manufacturing, 1982.

When water is consumed, it is no longer avai able for use by anyone else. This becomes problem when the total amount of wate ai able is less than what is required by each use To further complicate the equation, water us and water availability do not remain constan The availability of water changes from season t season and from wet year to drought. The de mand for water also changes with the season and over longer periods of time.

The DNR, Division of Waters is responsible fc resolving any situation where pumpage by on or more water users prevents other users fro obtaining adequate supplies of water. Thes interferences can occur with either ground c surface water sources, and procedures hav been established to handle both situations.

Ground water

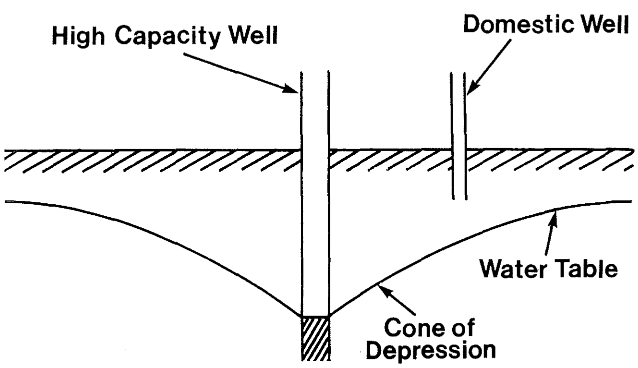
During the 1970's, ground water use conflic and well interference situations emerged highly volatile issues in ground wate management. The stresses created by the 197 77 drought and the increased use of groun water for irrigation brought these issues into th ublic consciousness. Prior to the 1977 lative session, there was no legal framework or dealing with these issues. High capacity well wners were not liable for the impact of their peration on nearby domestic wells. The 1977 egislation, and administrative rules which fol-owed, created a policy for resolving these ituations.

n most instances, conflicts over ground water ources occur under two sets of circumstances:

. **When a well is pumping, the water level of the pumped aquifer is lowered in a pattern around the well known as a cone of depression (Figure 28). Nearby wells within the cone of depression may experience lower water levels or run dry; this condition is referred to as a well interference. It is most often the case that the well causing the interference is a high capacity well with a lower priority for water use, while the affected wells are smaller domestic users with higher water use priority. Well interference problems are relatively localized, and the magnitude of a problem is determined by the rate of pumpage of the high capacity well, the condition of the affected well, and local geologic conditions. In a well interference ituation there are generally adequate supplies of ground water available, but the pumping of the production well interferes with the ability of the domestic well to capture the supply.**

. **A water conflict occurs when several wells pump from a ground water source with limited or inadequate reserves. The users may be of the same size and have the same priority of water use, but the combined water demands are greater than the capacity of the aquifer. In this case, the supply itself is threatened.**

Figure 28. Cone of Depression: Aquifer Response to Pumping



Most of the situations encountered in Minnesota involve the first set of circumstances - well interferences between high capacity wells (most often irrigation wells) and domestic wells. The goals of the DNR well interference procedures are to determine the validity of a complaint and to mediate a solution acceptable to all concerned parties. The procedures are designed to protect domestic well owners from interference caused by the high capacity withdrawals, while ensuring that high capacity well owners are not held liable for poorly constructed domestic wells not conforming to the state well code. The DNR evaluation of a well interference complaint usually involves inspections of the affected well(s) by a licensed well driller and collection of available information (such as drillers logs, observation well data) by DNR technical staff. The evaluation may require DNR staff to perform ground water investigations, modeling studies, test borings, or pumping tests to determine the impacts of the larger well on the capacity of the smaller well, and to evaluate feasible alternatives.

The results of the evaluation of a well interference complaint could be:

A. A determination that the complaint is not valid, i.e. that pumpage from the larger well does not significantly affect the domestic user. In this case, the complaint is dismissed, although the complainant (the domestic user) can take civil action against the large appropriator or request that the courts review the DNR decision; or

B. A determination that pumpage by the larger user does restrict the amount of water available to the domestic user. In this case, the larger user is notified that he or she is responsible for providing the domestic well owner with an adequate supply of water with the same quality and quantity as existed prior to the interference. At this point, the large user has four choices. He/she can:

1. Agree to restrict pumpage so that an adequate supply of water will be available to the domestic user. The DNR appropriation permit for the larger user would be modified to reflect the new pumping limits. This is acceptable only if there is assurance that the domestic water supply can be adequately protected.
2. Demand a public hearing contesting the facts, findings, and order of the DNR.

3. **Negotiate a reasonable settlement with the complainant. This is the preferred alternative. The settlement may involve improving the existing domestic well by deepening it, extending the drop pipe, or installing a new pump, or it may require drilling a new well. If the existing well does not meet Minnesota Department of Health standards, the complainant is responsible for some of the costs of drilling a new well.**
4. **Do nothing. If the large user does not respond to the DNR's notification of a valid complaint, the users appropriation permit is suspended.**

Since 1977, the DNR has received 76 well interference complaints regarding irrigation wells, and no complaints about an agricultural processing or livestock wells. The final disposition of these complaints are given in Table 14. Upon investigation by the DNR hydrologists and licensed well drillers, 34 percent of all complaints were dismissed as not valid and 36 percent of the domestic users were able to come to an acceptable agreement with the irrigators.

Table 14: Outcomes of Well Interference Complaints.

	Number
Complaint Withdrawn	10
Complaint Not Valid	26
Complaint Valid	
Negotiation Resolved	27
Limited Permit Issued	6
Permit Terminated	5
Total	38
Pending	2

Figure 29 shows the locations of these well interference complaints. Complaints have arisen in all parts of the state, except northeastern Minnesota, and in areas underlain by major aquifers as well as in areas with limited ground water reserves.

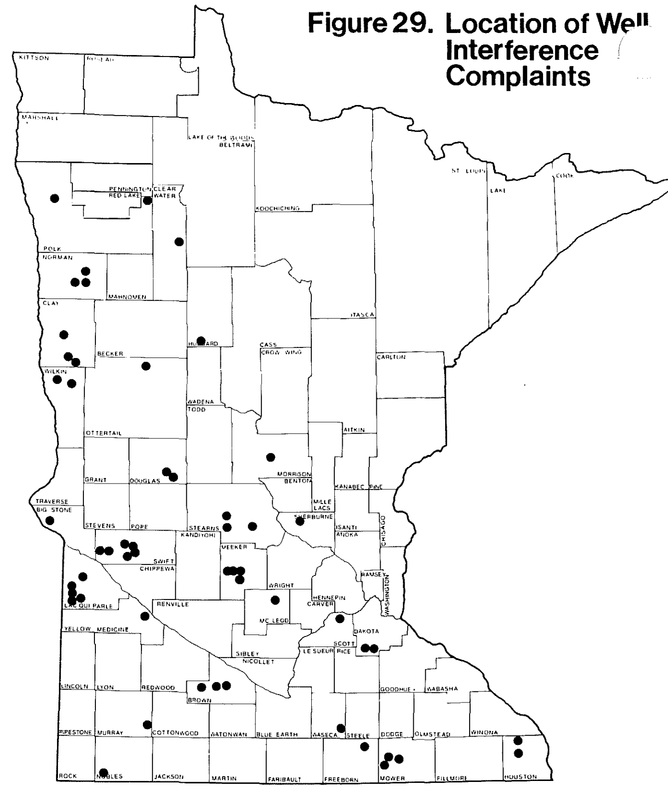


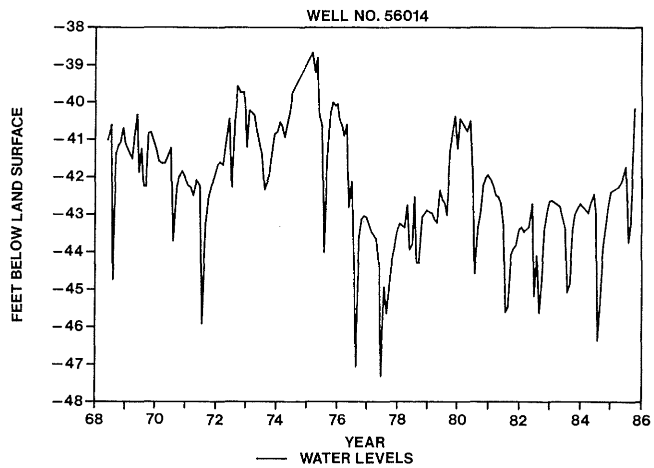
Figure 29. Location of Well Interference Complaints

The DNR well interference procedures are n often used to resolve water availability con among users who have the same priority of us The well interference procedures are of limite application where several wells compete for wa ter in an aquifer with limited or inadequate re serves (a **water use conflict** situation). The DN has a separate procedure for water use conflict An overriding concern of the DNR is that th aquifer not be *mined* - that is, that extende pumpage cannot permanently lower the wate below an acceptable level. In the case of co flicts, DNR staff examines the reasonableness the water use, the water use practices, and th possible alternative sources. The most desirab olution in this situation is to limit the rate of page for each well owner through modifica- of proposed and existing permits to a level t which all users are allocated an equitable ortion of the resource, and the water level of he aquifer is maintained at an acceptable level. f a solution is not possible through modi- ication, the DNR may terminate existing per- nits. If water users of different priority classes re involved, water is allocated based on elative priority of use.

Aining an aquifer arouses concern because it nplies that the rate at which water is being ithdrawn exceeds the long-term rate of echarge from precipitation. Prolonged mining ould deplete the aquifer until water is no onger available to any user. Often, it is difficult o detect when an aquifer is being mined; water evels can fluctuate widely in response to hanges in precipitation and nearby pumpage. ong-term monitoring of water levels is equired to distinguish between cyclical or hort-term fluctuations and permanent rawdown of the aquifer.

The DNR, in cooperation with the U.S. Geological Survey and local Soil and Water Conservation Districts, measures water levels in 600 wells located throughout the state. Measurement records are stored in computer datafiles maintained by the DNR. If the period of record is sufficiently long, plots of the depth to water over time reflect any changes in water availability at that location. Analysis of the plots (hydrographs) from several wells in the same aquifer can reveal changes in the amount of water stored in the aquifer.

Figure 30. Sample Hydrograph – Otter Tail County



A sample hydrograph from an observation well in Otter Tail County (Figure 30) shows the impacts of pumpage and precipitation on water levels. The sharp declines each year indicate the effects of irrigation water use during the summer. Note the rate at which the level returns to "normal" once pumpage stops. Seasonal changes are most evident when pumpage is minimal, as in 1969. Water levels are highest after spring rains, then reach minimum levels in winter. The impacts of a drought can be seen for the years 1976 through 1978. Spring maximums are greatly reduced, and several years of average precipitation are required before the aquifer is recharged to its pre-drought levels.

In its analysis of well levels, the DNR has found no evidence that pumpage for irrigation, livestock, or agricultural processing has resulted in the mining of aquifers anywhere in the state. However, the potential for mining exists, particularly in areas of intensive irrigation water use. Furthermore, this does not imply that local well interferences and ground water use conflicts will not occur. These conflicts occur even in years of normal and above normal precipitation.

Surface Water

Surface waters tend to be less dependable than ground water as a source for agricultural use. The demand for water generally peaks during the summer months, when streams and lakes are at their lowest levels. This combination greatly enhances the possibility for conflicts of over water use.

Both Minnesota law and DNR rules strictly limit the amount of water which can be taken from streams and lakes. Appropriations from lakes of less than 500 acres are discouraged. For any lake, the maximum combined withdrawal by all users cannot exceed the equivalent of six inches off the top of the lake. If there is potential for a conflict among irrigators taking water from a stream, then each irrigator is limited to no more than one-half acre-foot per acre of riparian land under his control (owned or leased). Only temporary appropriations may be authorized from designated trout streams. Finally, all surface water appropriation permit holders must submit a contingency plan describing alternatives to the use of their water source during periods of water shortage. If no alternatives exist, then the permit holders must agree to withstand the results of no appropriation.

In addition to the withdrawal limitations set forth in water appropriation permits, the DNR is required to establish protection elevations on the waterbasins from which the water is taken. This elevation is defined as "the water level of the basin necessary to maintain fish and wildlife habitat, existing uses of the surface of the basin by the public and riparian landowners, and other values which must be preserved in th public interest." (Minnesota Code of A Rules). No appropriations are authorized be this level.

Similarly, the DNR is authorized to establi protected flows on streams "to accommodate i stream needs such as water-based recreatio navigation, aesthetics, fish and wildlife habita water quality, and needs by downstream high priority users." (Minnesota Code of Agen Rules). At present, there are 43 streams f which protected flows have been established. the spring of 1987, the DNR requested fundi from the Legislative Commission on Minneso Resources in order to develop appropria procedures for the establishment of protecte flows on rivers with existing or potential wat use conflicts. It is expected that new protecte flows will be established and some existing flov re-evaluated as a result of this project.

The procedures for the resolution of a surfa water conflict are similar to those used resolve a ground water conflict. Authorizatio to use water is based on the establishe priorities of use and the number of acres of la owned or controlled riparian to the sour water. If the conflict involves users who are would be in the same priority class, then t users must develop a plan which will apporti the water among themselves. If the users cann agree to a plan or if the plan does n adequately protect the waters of the state, th the DNR may develop its own plan.

IMPACTS ON WATER QUALITY

Water, water every where,
And all the boards did shrink;
Water, water every where,
Nor any drop to drink
(Coleridge, *The Ancient Mariner*)

As the ancient mariner discovered, all t waters of the ocean cannot quench your thirst; the water quality is not suitable, you might well be surrounded by an ocean of sand. Wh Minnesota is far from any ocean, we are n immune to problems with water quality. Ofte however, these problems result not from acts nature but from our own hands.

;round Water Quality

..., degradation of the quality of Minnesota's ;round water resources has become a major oncern in recent years. Much of the focus is entered on non-point sources of contamination. 'he term *non-point* refers to the fact that no sin-;le facility, such as the outlet of a waste dis-harge pipe, can be identified as the source of he pollution. Non-point source pollution results rom wide-spread, low level contamination of ;round water from a multitude of diverse ources.

3oth crop and livestock production are major ion-point pollution sources. Fertilizers and pes-icides applied to agricultural cropland ercolate through the soil and into the inderlying aquifer. A recent study in Iowa oncluded that 30 to 50 percent of the nitrogen vhich was applied as fertilizer ended up in the ;round water (Short, 1986). Animal wastes vhich are concentrated in livestock feedlots can nter the ground water in the same manner as ertilizers and pesticides. The Minnesota 'ollution Control Agency has identified 1,500 inimal feedlot waste storage areas in the state, h of which is a potential site for ground vater contamination.

Since virtually all private drinking water upplies and most municipal supplies depend on ;round water, the health effects of non-point ource contaminants is of greatest concern. The nost widespread problems are associated with itrates. Nitrates have been shown to inhibit the bility of the blood to carry oxygen to the brain nd other vital organs. Unborn and newborn ba-ies are most sensitive to nitrates because of heir small body size and rapid brain develop-nent. This condition, known as methe-noglobinemia, or the "blue baby syndrome", oses a risk of brain damage if left untreated.

'hroughout Minnesota, natural concentrations f nitrate in ground water are extremely low, so ll existing levels in excess of the drinking water tandard (10 milligrams per liter) are assumed o be caused by human activities. The three kely sources of contamination are crop ertilizers, feedlots, and septic systems. Nitrates re extremely soluble in water and are not removed by natural processes. The only known methods of removal from drinking water are distillation and reverse osmosis, both of which are very expensive.

As scientists continue to study the problem of nitrate contamination, the link between nitrates and fertilizers appears to strengthen. For a time, concern was centered on southeast Minnesota, where it was thought that the karst topography of the region, with its many sink holes and underground caverns, would present the greatest opportunity for direct contamination via surface water runoff from feedlots or cropland.

Geologists now believe that up to 90 percent of the nitrates contaminating Minnesota and Iowa aquifers were applied to crops as chemical fer-tilizers and percolated downward through the soil with each rain (Short, 1986). Therefore the potential for contamination of ground water ex-ists wherever chemical fertilization occurs.

The presence of nitrate in ground water is an in-dication that other, more dangerous chemicals may also percolate downward through the soil. For years, the manufacturers of pesticides have contended that their products remain in the top few inches of soil and quickly decompose into more harmless chemicals. A study of surficial sand aquifers in central Wisconsin showed the presence of the insecticide Aldicarb in some ar-eas. Further investigation has shown that Aldicarb eventually decomposes in water, and by properly managing the timing and rate of application the problem can be controlled. Tests of ten wells in Winona County, Minnesota, showed traces of Lasso and Atrazine, two popular herbicides, in six of the wells (Short, 1986). A recent study by the Minnesota Departments of Health and Agriculture found one or more pesticides in 38 percent of all wells sampled (Klaseus, 1986).

The practice of conservation tillage, which has been encouraged over the years as a method of improving surface water quality by reducing the amount of erosion, may increase the degradation of ground water. Farmers who practice conservation tillage tend to use more pesticides in order to maintain crop yields. One study found an increase of between 14 and 43 percent in the use of herbicide and insecticide (Short, 1986). Further study is needed to ensure that we are not trading one water quality problem for another.

The use of irrigation presents some special concerns regarding ground water contamination. Irrigation is most common on coarse, sandy soils. Unlike clay, which has very fine, platy particles, sand particles do not readily adsorb individual molecules of pesticides and fertilizers. Adsorption would slow the movement of the contaminant through the soil into ground water, and thus allow more time for absorption into the plant or decomposition into less harmful chemicals. Instead, sand particles allow pesticides and fertilizer to pass through with relative ease. Moreover, the water applied to the soil through irrigation provides a medium to dissolve and transport these chemicals into the soil. The higher yields expected from irrigated land also require heavier applications of pesticides and fertilizer. The results of a study by the U.S. Geological Survey (Table 15) seem to indicate that irrigation is a greater threat to ground water quality than dry land farming.

Table 15: Nitrates in Shallow Ground Water (milligrams per liter).

Uncultivated	Cultivated	Irrigated	Residential
West Central Minnesota:			
2.5	3.4	14.0	NA
Anoka Sand Plain:			
0.15	1.8	5.6	2.8

(Uncultivated = apparently natural and undisturbed; Cultivated = non-irrigated row crops; Irrigated = irrigated row crops; Residential = homes with septic tanks; NA = not available).

A recent trend in irrigation has been the combined application of pesticides and fertilizer through the sprinkler system. This practice, known as chemigation, can reduce production costs by eliminating the need to apply th chemicals separately. Studies show chemigation may also reduce the total am of pesticides and fertilizer required to achiev comparable yields. The Department c Agriculture and the Department of Health no regulate the use of chemigation because of th potential for contamination of ground water a the well site. A well offers a direct pathway t the aquifer in the event of a spill or back syphoning by the irrigation pump. Therefore these agencies require the storage and mixing c chemicals at a set distance away from the wel and the installation of one-way valves o irrigation pumps to prevent any chemicals fron moving down the well into the ground water.

Surface Water Quality

Surface water quality problems can result fro both point and non-point pollution source Among agricultural water uses, point sources i clude a wide variety of poultry, meat, an vegetation processing facilities. Non-poi surface water pollution comes primarily fro runoff from animal feedlots and erosion c cropland.

Unlike non-point pollution sources, direct di charge of wastes into a lake or stream is strict regulated by the Minnesota Pollution Contr Agency. Thus, not only is the source of pollutio known, but limitations are set on the amount c pollution which can be discharged. Over the la 15-20 years, great strides have been made in r ducing the amounts of pollution discharged d rectly into the surface waters of the state. In r turn, the quality of many of our lakes and rive has remained constant or been improved duri this time.

Organic wastes from animal feedlots and ferti izer from cropland are a major source of surfac water pollution in many parts of Minnesota. Th nutrients in these materials cause an increase i plant growth while depleting the amount c available oxygen in the water. These change impair fish habitat and enhance the eutrophic tion of lakes.

The erosion of soils laden with pesticides m present a greater threat to water quality. Runo from cultivated fields can carry pesticides directly into streams or lakes. Higher concentrations of pesticide may enter surface water through accidental spills or improper disposal of leftover materials and their containers.

Even uncontaminated soils can degrade water quality by increasing turbidity and sediment deposition. Soil particles which remain in suspension reduce light penetration, thus decreasing plant photosynthesis and visibility for fish. Increased light absorption also increases water temperatures, making the environment less suitable to cold water animals such as trout. Deposition of sediment on rocky stream bottoms can limit the value of these nesting sites for several fish species (Warren, 1971).

Some experts claim that the recent farm crisis has resulted in an increase in the amount of soil erosion from agricultural land. Farmers who own their land have a strong incentive to minimize soil erosion in order to maintain soil fertility. If these farmers default on loans, the title to their land reverts to the lending institution, usually a bank, insurance company, or federal agency. These institutions may wish to generate some income from the property, so they commonly rent the land for farming. The renters, in turn, have less incentive to preserve the soil for future production, and more incentive to maximize their income for the term of their lease. Renters are more likely to abandon soil conservation practices and plant row crops from fence post to fence post. (Short, 1986). This change in production methods not only reduces the value of the land through soil loss but also degrades the quality of nearby surface waters.

Both the state and federal governments have recently implemented programs which they hope will reduce soil erosion and improve the quality of surface waters. The state Reinvest in Minnesota and the federal Conservation Reserve programs are designed to take highly erodible croplands out of production, accomplishing the dual purpose of reducing production surpluses while benefiting the environment.

Reinvest in Minnesota (RIM) allows farmers to sell permanent easements to the state for marginal and erodible lands. Participating farmers agree to plant trees, grasses, or other suitable cover on the land or allow water to return to former wetlands. Payments for the easements are funded through the sale of $16 million in state bonds. Farmers who do not wish to grant a permanent easement may also participate in a ten year set aside program. In both cases full payments are made soon after the completion of the contractual agreement.

The federal Conservation Reserve Program (CRP) authorizes ten year set aside agreements, but no permanent easements. Farmers submit bids on the amount of rent they will accept to remove erodible lands from production for ten years. The lowest bids are accepted for participation in the program. Payments are made annually, rather than at the beginning of the ten year period. This annual payment plans has discouraged many heavily indebted farmers who must maximize their income in order to make their loan payments.

Many questions have been raised regarding the ability of the federal program to remove the nation's most erodible lands from agricultural production. By offering only annual payments, CRP competes directly with existing government price support programs which may provide a better return. By requiring participating farmers to have owned the land for at least three years, CRP excludes farm renters, who may be less likely to use proper conservation practices. By excluding alfalfa from the list of qualifying crops, CRP may encourage dairy farmers who recently sold their herds to convert their alfalfa fields to row crops in order to generate more income. Given the amount of controversy surrounding this program, some changes in CRP are likely.

In Minnesota, RIM seems to garner more attention than CRP. Supporters of RIM have been careful to obtain the backing of sportsmen and conservation groups by emphasizing the parts of RIM which will improve fish and wildlife habitat. Debt-laden farmers have been attracted to the up-front payments for land easements. Renewal of RIM "unscathed" by the 1987 state legislature provides further evidence of its broad-based support in Minnesota.

CONCLUSIONS

Minnesota is highly dependent on agriculture for its economic well-being. Crop and livestock production, along with their associated processing facilities, are major sources of employment and income in the state.

Agricultural production requires large volumes of high quality water from both ground or surface water sources. In 1985, irrigation, livestock, and processing facilities accounted for 9% of all withdrawals and 23% of all water consumed in the state.

There was a dramatic increase in the use of irrigation during the 1970's in response to extremely dry weather conditions. Once irrigation systems were installed, many farmers began watering their crops during years of normal and above normal precipitation in order to increase yields. Since 1982, there has been little increase in the use of irrigation in the state. This is due to unfavorable economic conditions and above normal precipitation during this period.

Only 2.3 percent of all cultivated land in the state is irrigated, although the percentage is much higher for some crops, such as wild rice and potatoes. Corn is the most common irrigated crop, followed by soybean, alfalfa, and potatoes. Much of the fruits and vegetables grown for local markets, such as the Twin Cities metropolitan area, is irrigated. Over 70 percent of irrigation comes from ground water. Center pivots and travelling guns are the most common distribution systems used.

Most of the irrigation in the state occurs in the sandy soils of glacial outwash plains. The low water holding capacity of these soils makes them least tolerant to drought and most responsive to timely amounts of water during the hot summer months. Shallow aquifers capable of yielding sufficient quantities of water for irrigation tend to be located in these outwash plains or along river valleys. Counties with the greatest number of irrigated acres are Dakota, Otter Tail, Pope, Stearns, Sherburne, and Swift.

The production of wild rice is unique among agricultural crops in Minnesota. Irrigation is required because wild rice paddies are completely flooded during the spring. All wild rice irrigation uses surface water because of the large volumes necessary for production. Wild rice accounts for over 75% of all surface water withdrawals for irrigation. Major wild rice growing counties are Clearwater, Aitkin, Beltrami, Polk and Cass.

Future increases in the use of irrigation are primarily dependent on improvements in the farm economy. For most farmers in 1987, crop prices are too low to warrant the increased expense of a new irrigation system. The only other variable which might induce more irrigation is the weather. An extended period of low rainfall might convince some farmers that they need irrigation in order to generate any income from their land. Most new irrigation will use ground water from the aquifers which are capable of yielding more than 500 gallons per minute.

All agricultural processing facilities require some water for cleaning products, machinery, tools, and buildings. Some facilities use water for boiler feed make-up or incorporate water in the final product. Major water users include dairy, beverage, meat and sausage, poultry, and vegetable processors. The majority of these plants are located in southern Minnesota or near the Minneapolis-St. Paul metropolitan area. Some plants have their own sources of surface or ground water, other purchase their water from municipalities, while still others use both their own and municipal supplies.

The amount of water withdrawn by agricultural processors has declined over the last fifteen years. Part of this decline is due to a change in demand for meat products by American consumers. Withdrawals by some industries (such as sugar beets processing) have declines in response to limitations set by discharge permits issued by the Minnesota Pollution Control Agency.

There are some areas of the state where the consumption of water by livestock constitutes a significant portion of total withdrawals. The largest withdrawals are taken in Stearns County, a center for dairy and poultry production and also a major hog producer. Southern Minnesota along the Iowa border is also an important hog producing area, as well as the location of many beef cattle and turkey farms.

Virtually all of the water consumed by livestock comes from wells. Like agricultural processing, withdrawals for livestock consumption have declined over the last fifteen years due to a change in eating habits by the American consumer.

As with any withdrawal, the use of water for agricultural production can affect the availability of water for other users. The impacts of pumpage can vary from temporary water shortages affecting a limited number of users to steady depletions of water resources affecting many current and future water users over a broad geographical area. As the agency for managing the waters of the state, the DNR must develop and implement procedures to mitigate shortages caused by water pumpage.

Temporary shortages of ground water which result from withdrawals for agricultural production are not uncommon in Minnesota. In a typical well interference, pumpage from an irrigation well lowers the water table, causing one or more domestic wells in the vicinity to run dry. Resolution of the conflict usually involves the improvement of the domestic well, financed at least in part by the irrigation well owner.

The DNR maintains an extensive network of observation wells to monitor long-term changes in ground water supplies. Declining water levels in wells indicate that the rates of withdrawal exceed the amount of recharge to the aquifer from precipitation. To date, there is no evidence to indicate that water used for agricultural production has resulted in the mining of aquifers anywhere in the state.

Withdrawals for agricultural production most often affect surface water supplies when there are several users of single resource, and their collective withdrawals exceed the rate of flow into the lake or stream. In order to protect surface water resources for fish and wildlife habitat, recreation, and other instream uses, the DNR not only restricts the amount of water available to each user, but also establishes a minimum flow or level on the resource below which no withdrawals may take place.

Over the last twenty years, the implementation of stringent environmental regulations has greatly reduced the level of pollutants which enter lakes and streams from industrial and municipal discharge systems. As a result, concern for water quality has shifted to non-point pollution sources as the most significant threat to clean water. Typically, non-point pollution sources, including crop and livestock production, are not subject to regulations controlling the quality of the water which leaves their operations.

The most widespread problem associated with ground water quality comes from nitrates. While livestock feedlots and septic sewer systems are potential sources of nitrates, recent studies point to the use of nitrogen fertilizers as the primary means by which nitrates enter ground water. Nitrates have been shown to cause methemoglobinemia, or the 'blue baby syndrome' in infants.

Runoff from livestock feedlots and cultivated land carries nitrates, pesticides, and silt into lakes and streams. These materials degrade fish and wildlife habitat and destroy the value of the resource for recreation and for drinking water supplies.

The state of Minnesota has recently shown a commitment to the improvement of our surface water supplies with the implementation of Reinvest in Minnesota (RIM). This program promises to remove marginal and erodible lands from cultivation, thus helping to reduce our surplus of farm products while removing a major source of surface water pollution. Strong support from environmentalists, outdoor sports enthusiasts, and agricultural groups offer hope that RIM will provide a focus for water quality issues for years to come.

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