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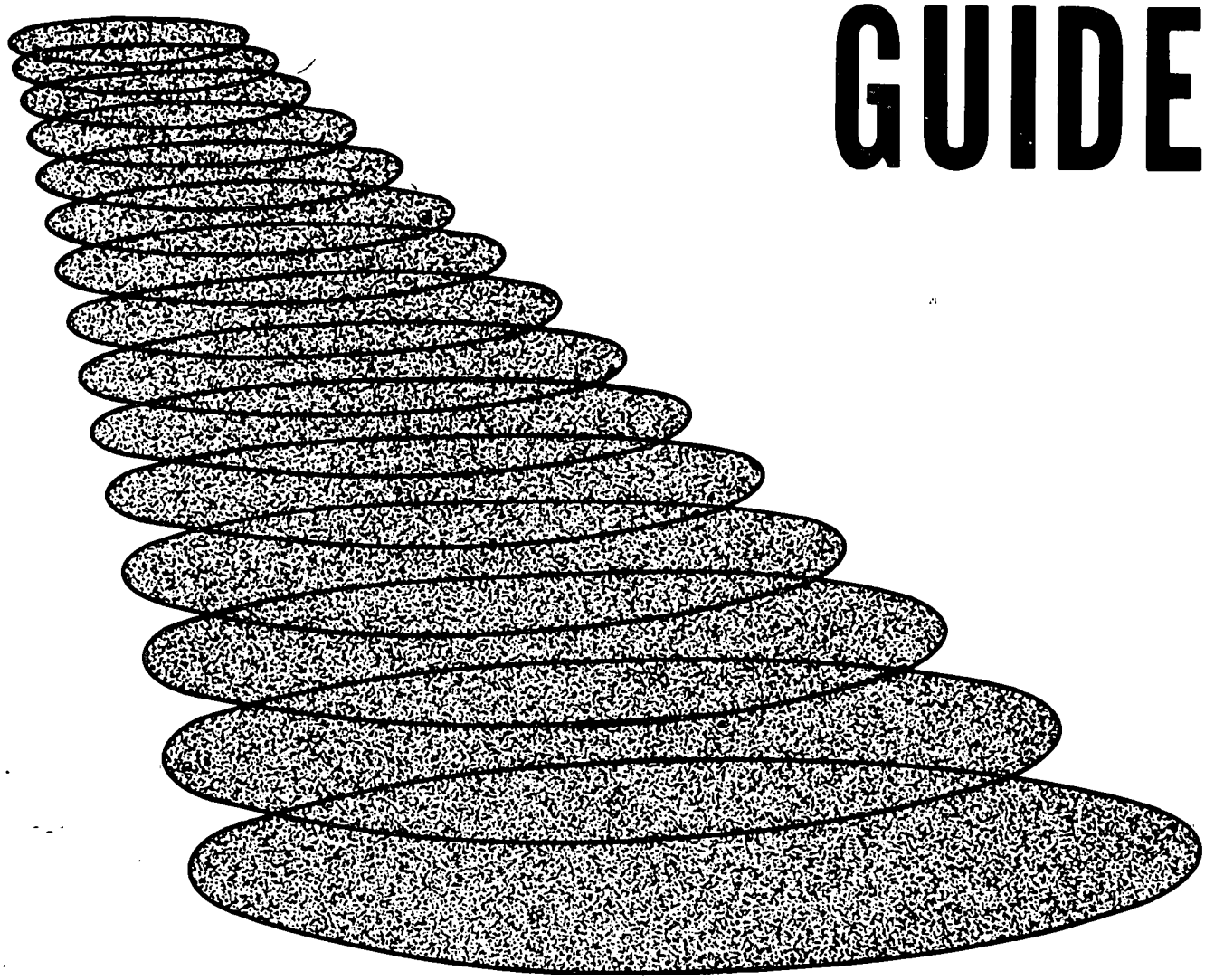
IRRIGATION GUIDE



FOR MINNESOTA

SOIL CONSERVATION SERVICE
U.S. DEPARTMENT OF AGRICULTURE
ST. PAUL, MINNESOTA
1976

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PREFACE

The Irrigation Guide for Minnesota was developed to help meet the needs of a rapidly expanding irrigation industry in the state. An attempt was made to make the guide comprehensive and flexible enough to permit the user to go from a review of basic irrigation principles to gathering detailed information for planning or design. It is felt that the guide is especially useful for considerations involved with the use of center pivot systems and volume gun systems.

Some of the soils information provided in the guide is generalized and therefore should be used with judgment. Actual on-site soils investigations should be conducted to determine specific site conditions such as depth of profile, and areal extent. For example, Irrigation Group 8 is described as a sandy loam, 12-20 inches over sand and gravel, excessively drained. It is necessary to know actual depths of sandy loam when planning and designing a system for a field that has been mapped as a soil in Irrigation Group 3. Depending upon the profile depth, the irrigation interval could vary as much as two to three days.

The guide was developed under the guidance of Harry M. Major, State Conservationist, and Robert C. Bintzler, State Conservation Engineer, Soil Conservation Service, USDA, St. Paul, Minnesota, and was prepared by:

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MINNESOTA IRRIGATION GUIDE

General

This guide has been prepared to assist those who are engaged in the planning, design and management of irrigation systems. It has been prepared for use in all areas of Minnesota. In order to account for the diversity of climate, the state has been divided into six (6) climatic areas as shown on Figure 1-1. The areas were determined by taking into account similarities in rainfall amounts, temperature patterns, length of growing season, and potential evapotranspiration rates.

The state of Minnesota covers 84,068 square miles, it measures about 400 miles north to south and averages 275 miles east to west. The climate of the state is continental. The mean annual temperature ranges from 36°F in the north to 47°F in the extreme southeast along the Mississippi River. Precipitation in Minnesota ranges from 19 inches annually in the northwest and gradually increases to 32 inches in the extreme southeastern portion of the state. About two-thirds of the precipitation falls in the five (5) month period from May through September. Figure 1-2 graphically illustrates the average monthly amounts of precipitation for three stations in the state.

Rainfall in Minnesota occurs on the average every seven to ten days (Figure 1-3). During the growing season, many of the storms are of such a high intensity that the infiltration rate of the soil is exceeded and runoff occurs or the soil profile is saturated, and water is lost through percolation below the root zone.

The annual consumptive use of a corn grain crop exceeds 20 inches. The growing season rainfall in Minnesota may not be too different from this figure. Recognizing that a significant portion of the rainfall will be lost as runoff or deep percolation and that rainfall will not occur at an interval to meet the crop needs, it becomes apparent that irrigation is necessary to realize the maximum possible yields, especially on soils with a low available water holding capacity.

The guide does not attempt to make recommendations relating to economic evaluations of irrigation as to crops or types of system. The economics of irrigation is usually an individual field or farm determination. Generally, successful irrigation is complementary to and depends upon drainage and erosion control being adequately treated. The need for additional erosion control or drainage should be kept in mind while planning an irrigation system. Basic factors that must be considered when planning an irrigation system are:

1) AWC of the soil
2) Soil depth and rooting depth of crop
3) Slope (runoff and erosion hazard)
4) Intake Rate

5) Need for drainage; depth to water table
6) Salinity
7) Susceptibility to stream overflow
8) Stoniness
9) Susceptibility to wind and water erosion
10) Topography; suitability for type of irrigation and need for leveling
11) Water supply; type, quantity, and quality

Sprinkler irrigation is the primary type of irrigation covered in the guide. Surface irrigation and special use of sprinkler irrigation equipment is mentioned but not in the detail that sprinkler irrigation is presented.

Crops

Only the commonly irrigated crops are shown in the guide. Recommendations for specialty crops or other crops involving limited acreage may require additional assistance from the SCS State Staff or the Agricultural Extension Service.

Irrigated crops shown in the guide are listed in Tables 2-1A through 2-6C.

Soils

Each soil type has its own water intake characteristics and water holding capacity. The differences, however, are sufficiently minor that for practical purposes general soils can be grouped together. The soils in Minnesota have been divided into 26 groups called Irrigation Groups. Chapter III contains the soil group listings and tables of water holding capacity and intake rates.

Water Supply

A supply of water adequate for the demands of the crops to be irrigated must be available when needed. Water supply is often the controlling factor in irrigation feasibility and the number of acres that can be irrigated. Figure 1-4 shows areas within the State where a detailed appraisal of ground water for irrigation has been completed by the U.S.G.S. and Minnesota D.N.R. In addition, the U.S.G.S. has published Hydrologic Atlases in the areas indicated on Figure 1-5. Either of these studies should be used for planning in a specific area if the report is available. For broad planning or preliminary planning, Figure 1-6 may be used to indicate the potential of sand and gravel deposits as a ground water supply. Figure 1-6 is a generalized map of Minnesota showing the location and extent of surficial sand deposits. This map shows probable well yields that may be representative of an average well in an area. Wide variation from the yield values shown can occur locally.

In all of the areas of the surficial sand deposits there will be many places where adequate yields for irrigation are not available

from the sand-plain aquifers. In some of these areas, yields may be available from buried drift aquifers or bedrock. Where drift is thick, the chance of penetrating a buried drift aquifer should be greater than where the drift is thin. However, in some places, for example the southwest part of the State, test holes locally have penetrated several hundred feet of drift to bedrock without finding any water-yielding zones. Even where buried drift aquifers are penetrated and yield more than 100 gallons per minute, in many instances recharge to a buried aquifer is a limiting factor that may limit extensive development. Paleozoic bedrock in the southeast, commonly yields hundreds and locally may exceed a thousand gallons per minute. See Figure 1-7 for the bedrock geology in Minnesota. Throughout the rest of the State bedrock locally may yield 100 gallons per minute. Even where wells in Cretaceous or crystaline bedrock yield 100 gallons per minute, recharge to the aquifer will be the controlling factor on irrigation development. Other uses, notably municipal and domestic use, may already stress the bedrock system in many areas so that withdrawal for irrigation may not be practical.

A water supply must not only be available in quantity, it must be of satisfactory quality for irrigation. That is, it must not have a detrimental effect on the crop, soil, or equipment.

Poor quality water is caused by excess chemical content or by mineral impurities such as silt or sand. The most common chemicals are salts, chlorine, boron, organic acids, and industrial wastes. Silt may be present in surface water supplies and sand is often a problem from wells that have been improperly designed or constructed. Figure 1-8 depicts areas of Minnesota where dissolved solids in the ground water are greater than 1,000 milligrams per liter. A laboratory analysis should be made of all proposed sources of water to be used for irrigation before large sums of money are spent on development of the system. This is true not only for the areas shown in Figure 1-8, but for the remainder of the State also. Generally, water containing more than 500 mg/1 of total dissolved solids is not recommended if another source of water is available.

Well Design

A qualified irrigation well driller should be consulted when ground water supplies are to be used for the water supply. Exploratory drilling should be done to log and sample the aquifer in order to properly design the well screen and gravel pack. A qualified driller will know how to develop the well to its maximum efficiency. Reference may be made to the Agricultural Extension Service, University of Minnesota Bulletin M-158, 1972, "Irrigation Wells", for a more detailed discussion of wells and well design.

DEFINITION OF TERMS

Consumptive Use

Consumptive use, often called evapo-transpiration, is the amount of water used by the vegetation in transpiration and building of plant

tissue and that evaporated from adjacent soil or intercepted precipitation from plant foliage. If the unit of time is small, consumptive use is usually expressed as acre inches per acre or depth in inches, whereas, if the unit of time is large, such as a growing season or a 12-month period, it is usually expressed as acre feet per acre or depth in feet.

Consumptive Water Requirement

The amount of water potentially required to meet the evapo-transpiration needs of vegetative areas so that plant production is not limited from lack of water.

Effective Rainfall

Precipitation falling during the growing period of the crop that is available to meet the consumptive water requirements of crops. It does not include such precipitation as is lost to deep percolation below the root zone nor to surface runoff.

Net Irrigation Requirement (Net water application)

The depth of irrigation water, exclusive of precipitation, stored soil moisture, or ground water, that is required consumptively for crop production and required for other related uses. Such related uses may include water required for leaching, frost protection, etc.

Peak Period Consumptive Use

Peak period consumptive use is the average daily rate of use of a crop occurring during a period between normal irrigations when such rate of use is at a maximum.

Irrigation Efficiency

The percentage of applied irrigation water that is stored in the soil and available for consumptive use by the crop. When the water is measured at the farm headgate, it is called farm-irrigation efficiency; when measured at the field, it is designated as field-irrigation efficiency; and when measured at the point of diversion, it may be called project-efficiency.

Gross Irrigation Requirement (Gross water application)

The net irrigation water requirement divided by the irrigation efficiency.

Field Capacity

The moisture percentage, on a dry weight basis, of a soil after rapid drainage has taken place following an application of water, provided there is no water table within capillary reach of the root zone. This moisture percentage usually is reached within two to four days after an irrigation, the time interval depending on the

physical characteristics of the soil and the effect of the growing crop.

Wilting Point

The wilting point is the moisture percentage, also on a dry weight basis, at which plants can no longer obtain sufficient moisture to satisfy moisture requirements and will wilt permanently unless moisture is added to the soil profile.

Carryover Soil Moisture

Moisture stored in soils within root zone depths during the winter, at times when the crop is dormant, or before the crop is planted. This moisture is available to help meet the consumptive water needs of the crop.

Irrigation Frequency

Refers to the allowable numbers of days between irrigations. It depends on the consumptive-use rate of a crop and on the amount of available moisture in the root zone (moisture extraction depth) between field capacity and the starting moisture level for irrigation. Irrigation period refers to the number of days a system, of given capacity, takes to irrigate the design area. Irrigation period should always be equal to, or less than, irrigation frequency.

Available Water Holding Capacity (AWC)

Available water holding capacity is the amount of water the soil will hold between field capacity and the permanent wilting point.

Maximum Application Rate

Is the maximum rate that water can be applied to a soil during the time required for the soil to absorb the depth of application without runoff for the conditions of soil, slope and cover.

Irrigation Depth

Is the soil depth used to determine irrigation water requirements for design of systems. A high moisture level must be maintained in this depth for top production of crops. It is not necessarily the maximum root depth for any given plant.

Crop Growth Stage Coefficient

A factor that modifies the Blaney-Criddle Formula which reflects the type of plant and stage of growth on consumptive use.

REGULATION OF WATER USE FOR IRRIGATION

A permit must be obtained from the Commissioner of the Department of Natural Resources before any waters of the State can be withdrawn and used for irrigation under authority contained in Minnesota Statutes Chapter 105.

The Division of Waters, Soils and Minerals has been designated by the Commissioner of Conservation to be responsible for processing and issuing permits for this purpose. Applications for permits to use water for irrigation may be obtained from the Director, Division of Waters, Soils and Minerals, Department of Natural Resources, Centennial Building, St. Paul, Minnesota 55101.

DIVISION OF WATERS, SOILS AND MINERALS POLICY REGARDING WATER WITHDRAWAL AND USE FOR IRRIGATION

Underground Waters

Permits for the withdrawal and use of underground waters, from wells, pits, and sumps will be issued on the basis of reasonable use. The amount of water considered to represent reasonable use will depend primarily upon the acreage of lands involved, crops, climatic characteristics of the area, and the dominant soil types of the acreage to be irrigated. Each application for a permit will be evaluated on an individual basis and all reasonable requests for use of underground waters will be considered. The maximum quantity of water allowed to be withdrawn is based on the most detrimental drought conditions that can be expected to occur in a given area based on an analysis of past weather records as determined by the University of Minnesota.

Surface Waters

Permits for the withdrawal and use of surface waters, from lakes, streams, and ponds, are issued on the basis of reasonable use and the ownership of lands abutting the surface water source. Since the irrigation season usually coincides with the season of lowest stream flows and lake levels, it is necessary to place restrictions on the amount of water withdrawn and used from these sources for irrigation. Each property owner having land abutting (riparian to) a lake, stream or pond has certain legal rights (riparian rights) concerning the water contained therein. The policy existing at the date of this publication regarding the withdrawal and use of surface water restricts the amount of water which can be withdrawn to a maximum allowable use of 6 inches per acre per year based on 40-acre tracts or government lots which are adjacent to the surface waters. Thus a farmer owning a 40-acre tract of land abutting a lake or stream may withdraw a maximum of 20 acre-feet or 6 inches for each acre in each year. Obviously, there are many streams and some lakes which could not provide sufficient water if each property owner having land abutting the streams or lakes attempted to withdraw the maximum allowable amount. In many instances the smaller streams would be

dry and the lake levels would be lowered excessively. It is recommended that anyone considering an irrigation enterprise should carefully investigate the availability of underground water before attempting to obtain a permit for use of surface waters.

Because of the public interest in our lakes and streams and the legal problems concerning them, the policy regarding surface water withdrawal and use for irrigation is continuously being evaluated and may be changed in the near future. In certain cases where public water supplies and waste disposal facilities may be adversely affected by withdrawals of water for irrigation, special restrictions concerning pumping rates and quantities of water may be imposed to protect the public interest.

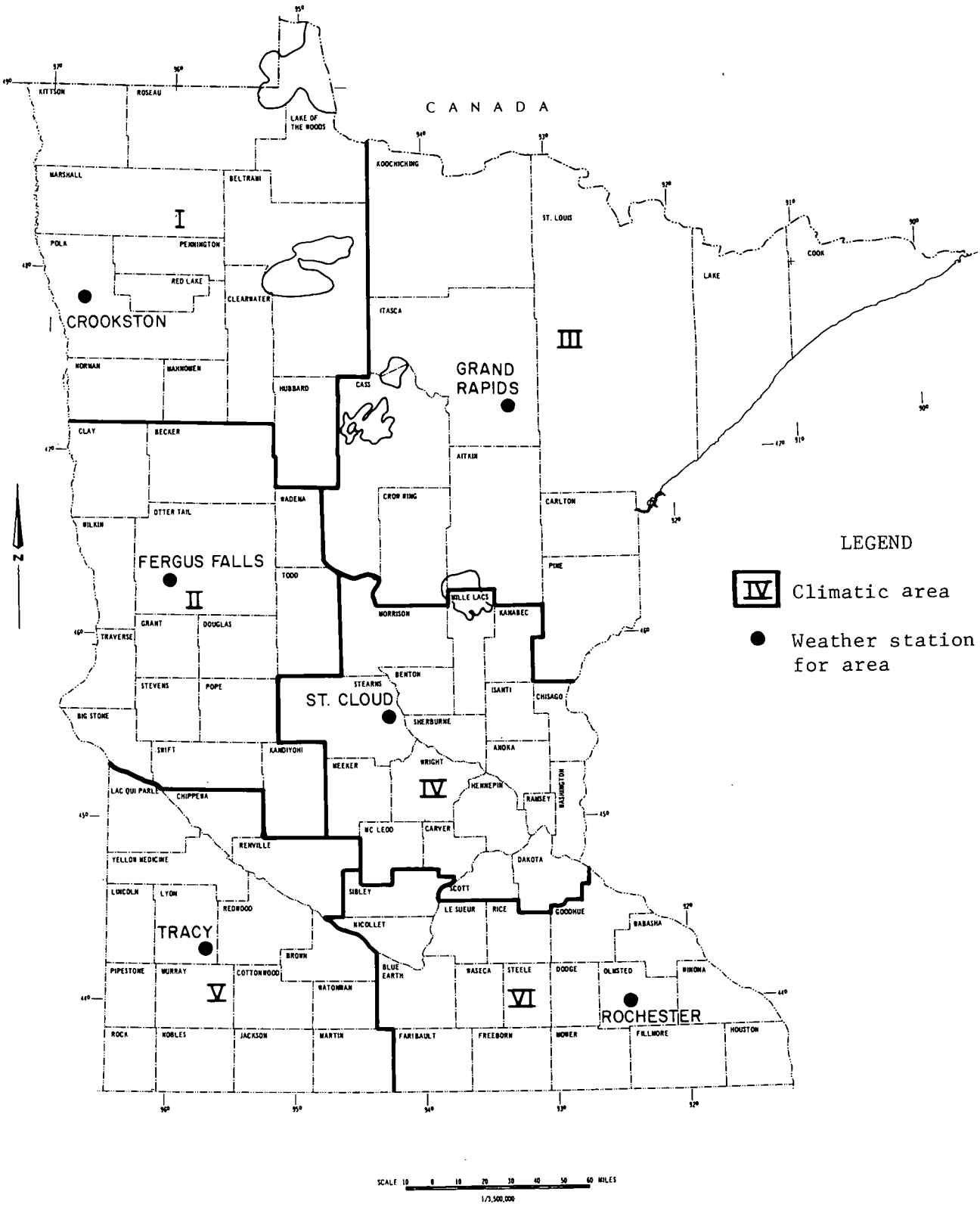

Figure 1-1. Climatic Areas For Irrigation.

SOURCE: FAMILY OF MAPS SCS DRWG. NO. 5,S-32,926(4-10-75)
AND INFORMATION FROM FIELD TECHNICIANS.
ALBERS EQUAL AREA PROJECTION

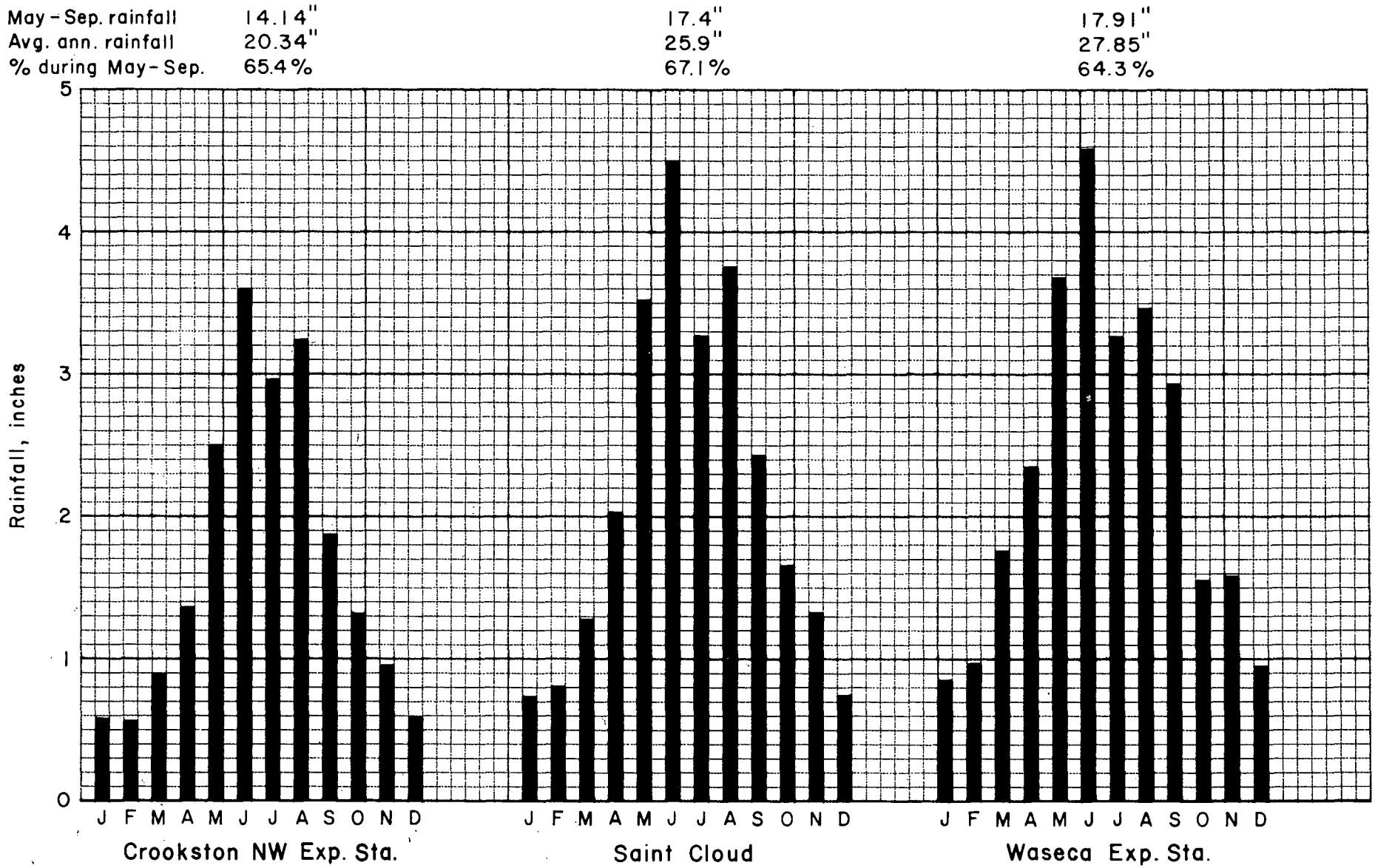

Figure 1-2. Annual Rainfall Distribution

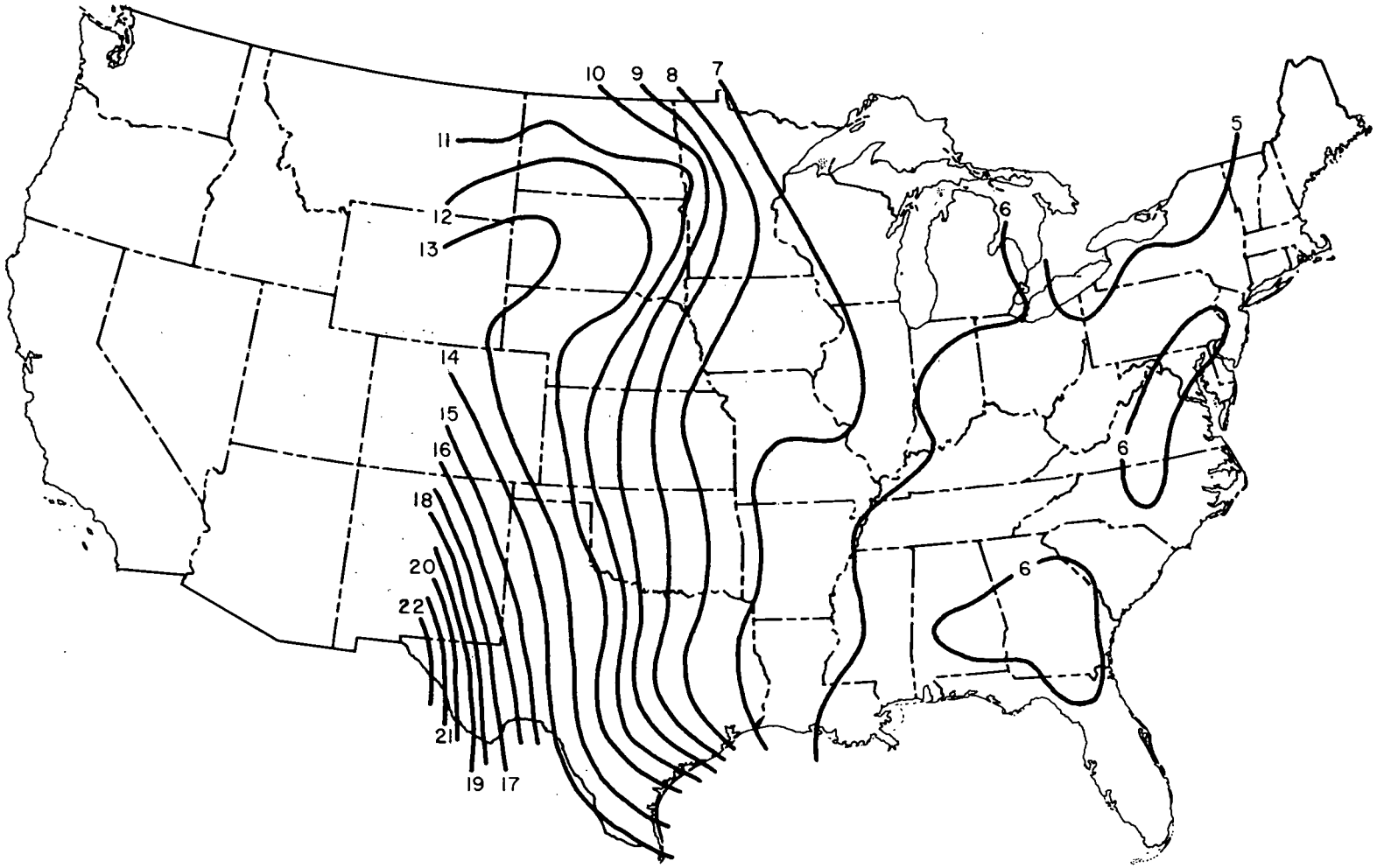

Figure 1-3. Average number of days between rains to be expected in some areas of the United States. (Data were not available for the western parts of the country.) "Generalizing Dry-Day Frequency Data;" David M. Hershfield; American Water Works Journal, 1969.

MAP COPIED FROM "PLANNING FOR AN IRRIGATION SYSTEM" PUBLISHED BY AMERICAN ASSOCIATION FOR VOCATIONAL INSTRUCTIONAL MATERIALS, IN COOPERATION WITH SCS, USDA.

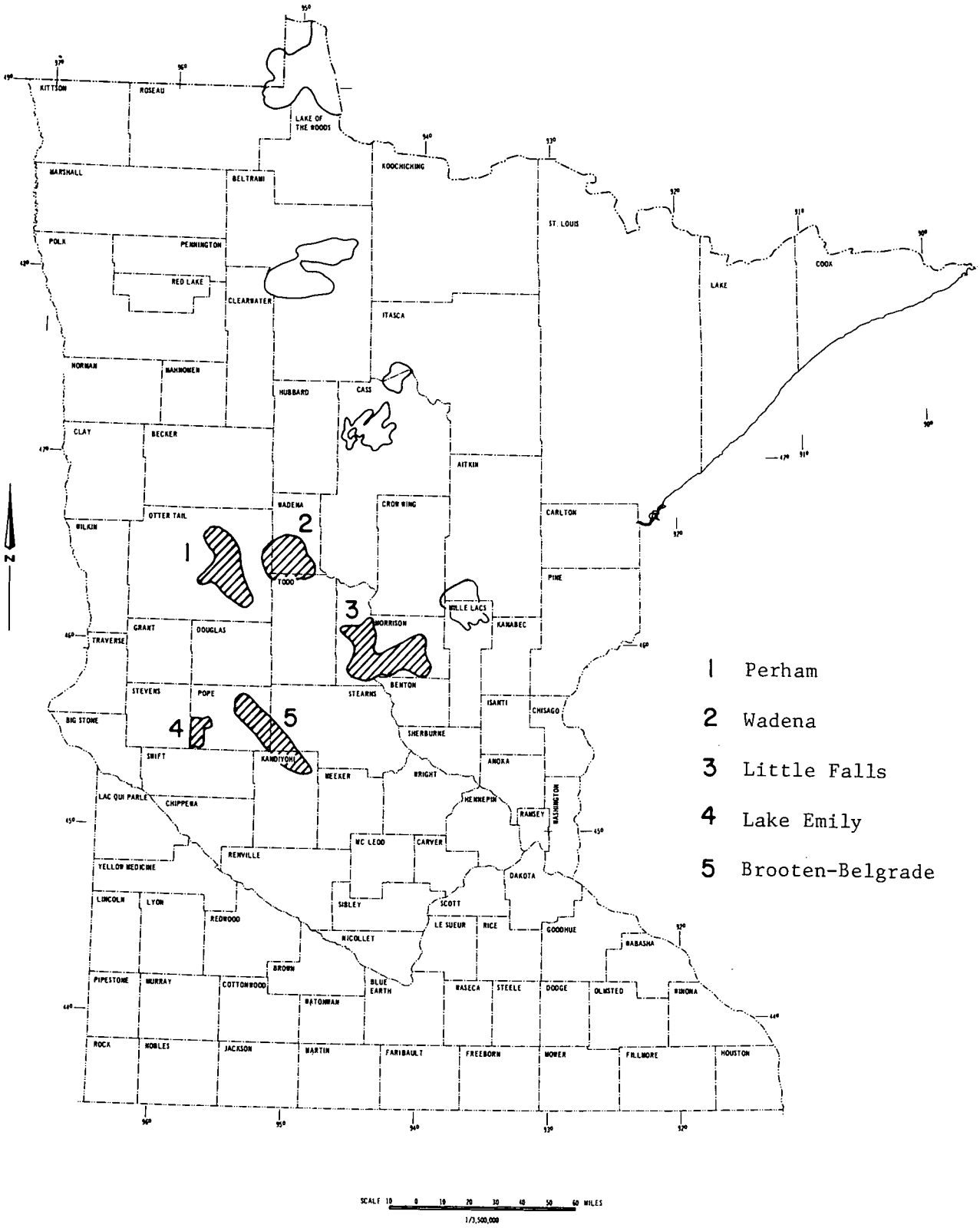

Figure 1-4. Locations of USGS Detailed Groundwater Studies.

SOURCE: FAMILY OF MAPS SCS DRWG. NO. 5,S-32-926(4-10-75)
AND INFORMATION FROM FIELD TECHNICIANS
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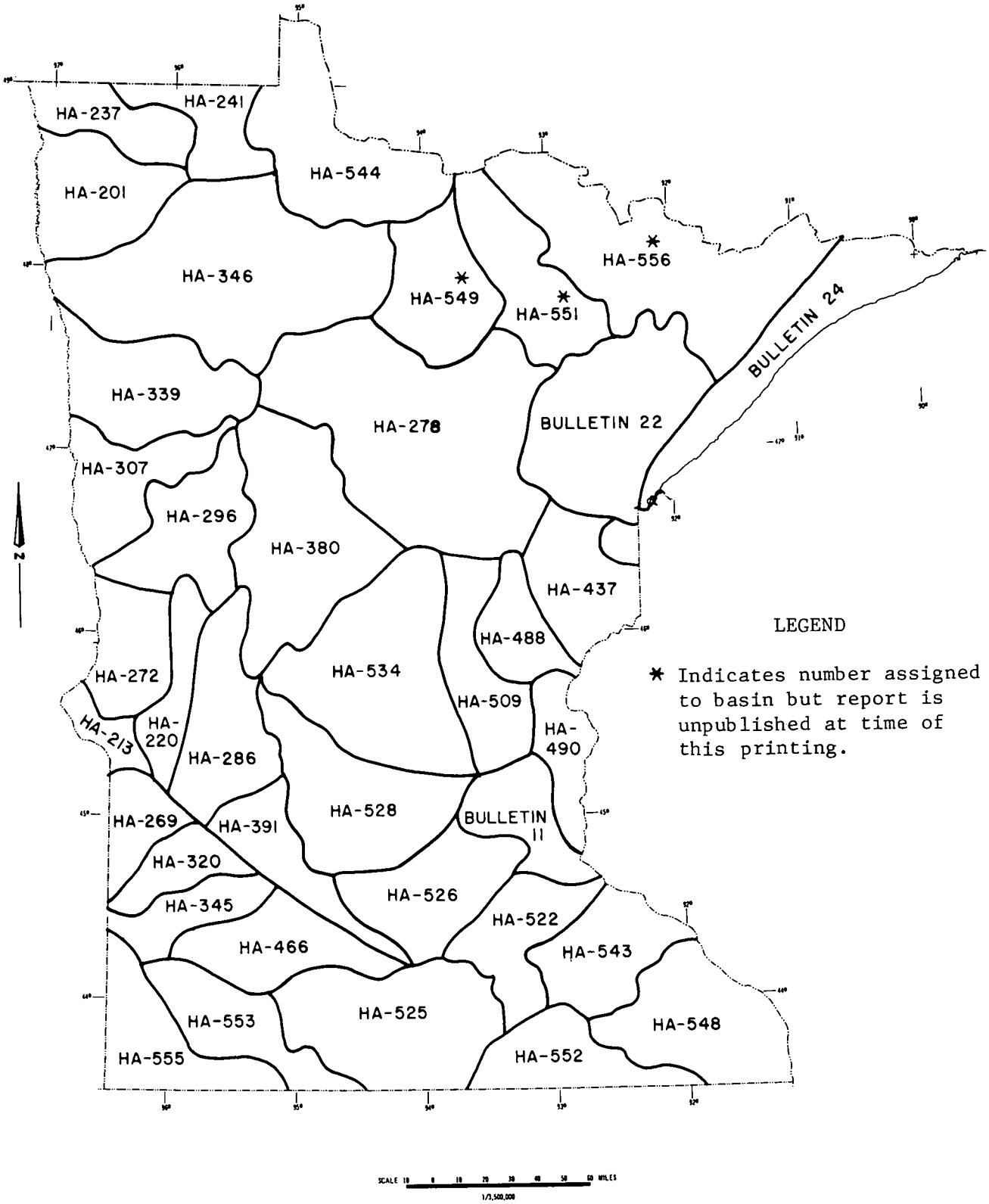

Figure 1-5. Completed Hydrologic Atlas - USGS.

SOURCE:
FAMILY OF MAPS SCS DRWG. NO. 5,S-32,926(4-10-75)
AND MAP OF COMPLETED HYDROLOGIC INVESTIGATIONS
IN MINNESOTA PUBLISHED BY THE U.S. GEOLOGICAL SURVEY.
ALBERS EQUAL AREA PROJECTION

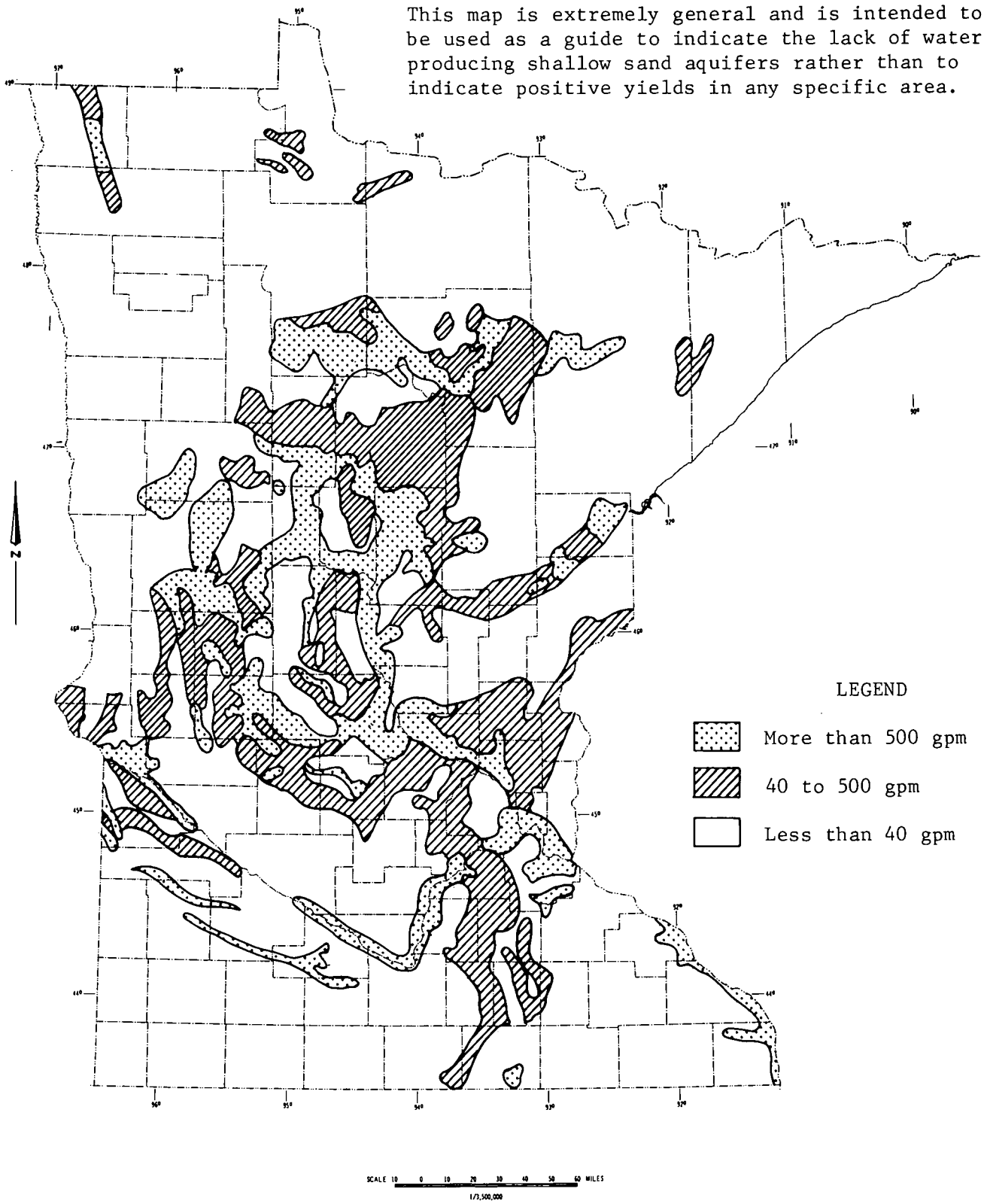

Figure 1-6. Generalized Map of Minnesota Showing Ranges of Probable Well Yield From Sand and Gravel Deposits.

SOURCE:
FAMILY OF MAPS SCS DRWG. NO. 5,S-32,926(4-10-75)
AND COMPILATION OF DATA PUBLISHED SEPARATELY IN
THE UPPER MISSISSIPPI, GREAT LAKES, SOURIS-RED-RAINY,
AND THE MISSOURI RIVER BASIN STUDIES. ALBERS EQUAL
AREA PROJECTION.

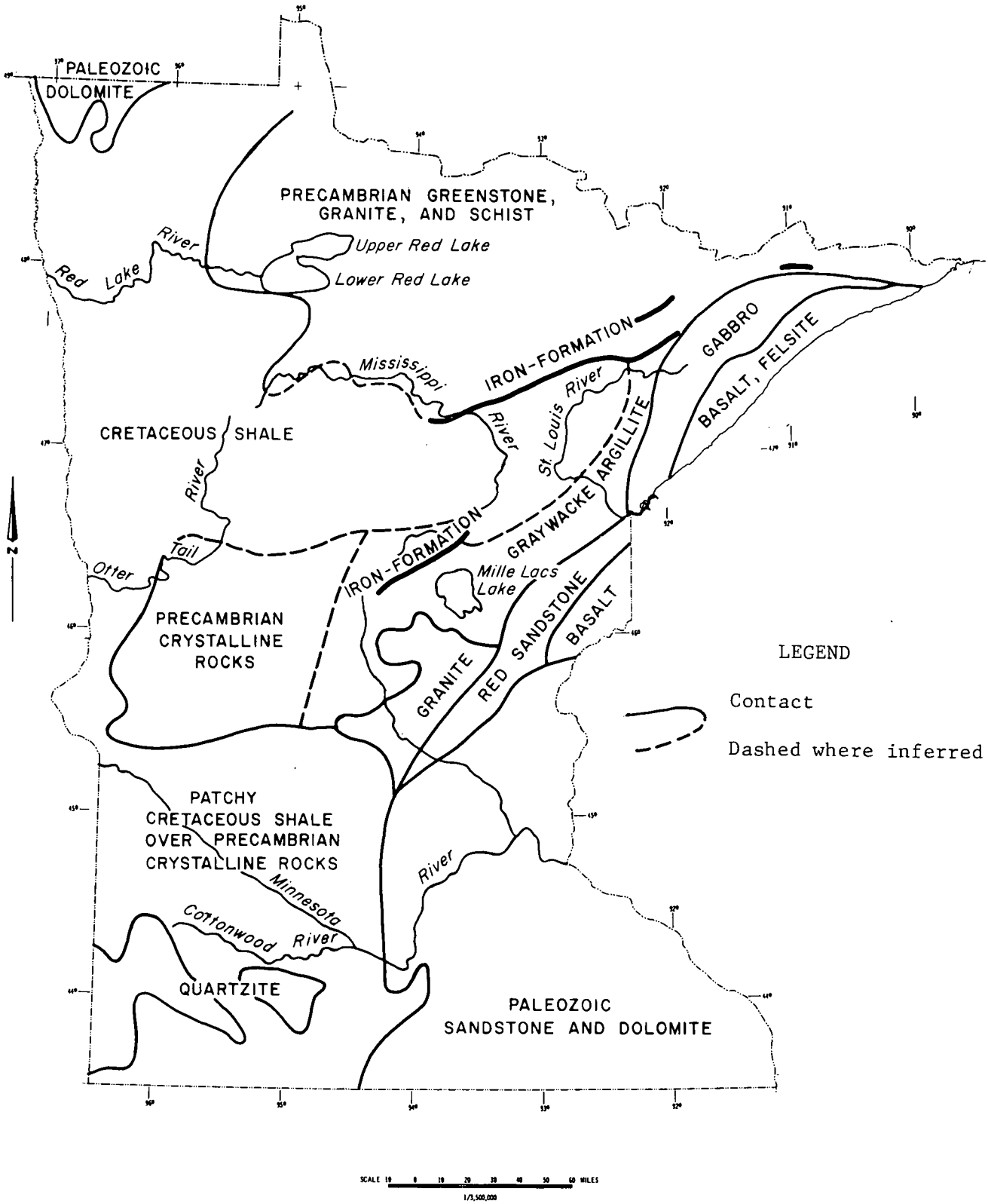

Figure 1-7. Bedrock Geology.

SOURCE:
FAMILY OF MAPS SCS DRWG. NO. 5,S-32,926 (4-10-75) AND MAP REPRODUCED FROM BULLETIN 26 "THE NATURAL QUALITY OF GROUNDWATER IN MINNESOTA", MINNESOTA DIVISION OF WATERS, SOILS, AND MINERALS, DNR, APRIL, 1974. ALBERS EQUAL AREA PROJECTION.

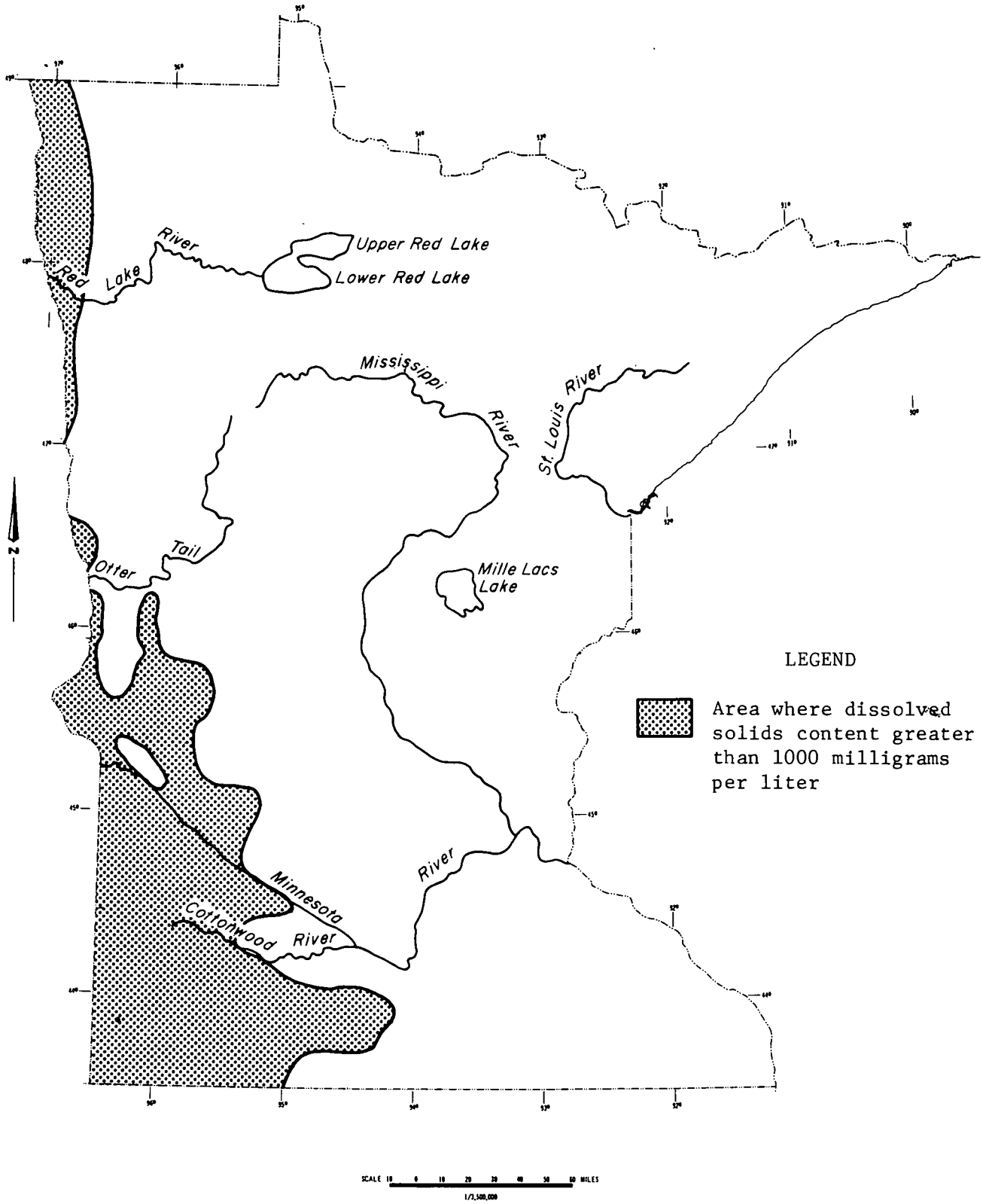

Figure 1-8. Areas of Highly Mineralized Ground Water.

SOURCE:
FAMILY OF MAPS SCS DRWG. NO. 5,S-32,926 (4-10-75) AND MAP REPRODUCED FROM BULLETIN 26 "THE NATURAL QUALITY OF GROUNDWATER IN MINNESOTA", MINNESOTA DIVISION OF WATERS, SOILS, AND MINERALS, DNR, APRIL, 1974. ALBERS EQUAL AREA PROJECTION

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CROPS AND CONSUMPTIVE USE

Consumptive use, often called evapotranspiration, is the amount of water used by the vegetative growth in transpiration and building of plant tissue and that evaporated from adjacent soil or intercepted precipitation on the plant foliage.

The stage of a crop's growth has a very considerable influence on its consumptive use rate. Annual crops have three rather distinct stages of growth. These are: (1) emergence and development of complete vegetative cover during which time consumptive use rate increases rapidly from a low value and approaches its maximum; (2) the period of maximum vegetative cover during which time the consumptive use rate may be near or at its maximum if abundant soil moisture is available; and (3) crop maturation where the consumptive use rate begins to decrease. During the latter period, the plant becomes the limiting factor in the transpiration rate.

In Minnesota, few measurements of consumptive use are available, and it is necessary to estimate consumptive use of crops from climatological data. Soil Conservation Service Technical Release 21 contains the criteria used to compute consumptive use. TR-21 employs a modification of the Blaney-Criddle formula.

Effective rainfall supplies a portion of the consumptive use by crops. It may be a major portion in humid areas. Since there are no records of effective rainfall available, it is necessary to utilize total rainfall records and estimate the portion of total rainfall that is effective.

In Minnesota, storms of large magnitude and high intensity occur during the growing season. These storms often produce water in excess of the soil intake rate or the volume exceeds that which can be stored in the soil profile for consumptive use. This excess is lost either to surface runoff or to percolation below the root zone depth. When consumptive use rate of a crop is high, available moisture in the soil profile is depleted rapidly, providing storage capacity for receiving rainfall. Conversely, when the consumptive use rate is low as in the spring and fall, storage capacity may be limited and fields may be wet for extended periods of time.

Net irrigation requirements are shown in Tables 2-1A through 2-6C based upon the 50% and 80% chance of effective rainfall and a three-inch net depth of application of irrigation water. Since the effective rainfall is directly related to the available water holding capacity of the soil, adjustments need to be made for other net application depths. Refer to the example following Table 2-6C, which illustrates adjustments made for a net application of 1.0 inch.

There is a greater chance for rain to fall on a soil at a time when it is capable of holding a large amount of rainfall if the irrigation frequency is relatively long. This can only be accomplished by applying near the maximum allowable net application. Hence, when

the net application of irrigation water is large, a larger percentage of the total rainfall will be effective. For net irrigation applications other than three inches, the effective rainfall shown on Tables 2-1A through 2-6C must be multiplied by the correction factor given below:

Net Depth of Application	.75	1.0	1.5	2.0	2.5	3.0	4.0	5.0
Factor	.72	.77	.86	.93	.97	1.00	1.02	1.04

When the amount of effective rainfall is reduced because of using less than a 3-inch net depth of application, the net amount of irrigation water required must be increased accordingly. Likewise, if the net depth of application is more than 3 inches, the net amount of irrigation water required may be decreased by the same amount.

To determine the amount of irrigation water that should be applied each month, it is necessary to consider the following:

1. The amount of water necessary to fill the root zone to field capacity.
2. The amount to be added to each months needs because of losses in application. This will vary with soils, the irrigation system and field efficiencies.
3. The amount applied near the end of the use season may be decreased an amount equal to the stored moisture which is available.
4. The time of water application will precede the use period by the amount of available water the root zone of the crop will hold.

The net water to be replaced during a normal irrigation is usually taken as 50 percent of the available moisture holding capacity for the irrigation root depth. This can be determined by referring to table 2-8 to find the irrigation depth of the particular crop and Chapter 3 for the available water holding capacity. The AWC is multiplied by the percent depletion, usually 50 percent, to find the net amount of water to be replaced at a normal irrigation. Additional water must be added to compensate for evaporation losses, uneven distribution, and interception by foliage. This is known as irrigation efficiency. Table 4-5 on page 4-25 gives design efficiencies for sprinkler systems. Net water to be replaced divided by efficiency is the gross application required. For example:

Given: Soil - Pomroy (Irrigation Group 4)
Crop - Corn

From Table 2-8, page 2-25, depth to irrigate - 3 feet. From page 3-13, Chapter 3, the available moisture holding capacity in the irrigation depth is 3.76. The net water to be replaced is (3.76 x 0.5) 1.88 inches. Table 4-5, on page 4-25 shows an efficiency of 75 percent

assuming a center pivot system will be used. The gross application is 1.88/.75 or 2.51 inches of water.

The irrigation frequency during peak period use may be calculated by this formula:

$$\frac{\text{Net irrigation application}}{\text{Peak period daily use}} = \text{Irrigation frequency in days.}$$

For this example, the net water to be replaced is 1.88 inches. From Table 2-7 on page 2-24 the peak period use rate is .30 inches per day in climatic area 2.

$$\text{Irrigation frequency} = \frac{1.88 \text{ in.}}{0.30 \text{ in/day}} = 6.27 \text{ days}$$

Tables 2-1A through 2-6C show the estimated seasonal and monthly consumptive use of various crops in each of the climatic areas.

Table 2-7 shows peak consumptive use values to be used for system design.

TABLE 2-1A

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 1

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Potatoes		Average Growing Season Dates: May 15 - September 15			
May	0.62	0.57	0.43	- -	- -
June	2.97	2.31	1.74	- -	- -
July	6.86	2.35	1.77	3.71	5.01
August	6.84	2.59	1.95	3.90	4.70
September	1.80	0.65	0.49	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	19.11	8.48	6.39	7.62	9.72
Crop: Sugar Beets		Average Growing Season Dates: May 10 - October 10			
May	1.13	0.94	0.71	- -	- -
June	3.50	2.43	1.83	- -	0.59
July	6.58	2.28	1.71	4.06	4.86
August	6.82	2.59	1.95	4.23	4.87
September	3.72	1.32	0.99	1.17	1.57
October	0.54	0.27	0.20	- -	- -
Season Total:	22.32	9.85	7.41	9.47	11.90
Crop: Corn, Grain		Average Growing Season Dates: May 15 - October 15			
May	1.05	0.67	0.51	- -	- -
June	3.82	2.47	1.86	0.22	1.00
July	7.44	2.33	1.75	5.11	5.68
August	7.44	2.65	1.99	4.79	5.44
September	3.89	1.33	1.00	1.49	1.92
October	0.85	0.41	0.30	- -	- -
Season Total:	24.50	9.88	7.44	11.62	14.06
Crop: Corn, Sweet		Average Growing Season Dates: May 15 - August 10			
May	1.00	0.80	0.60	- -	- -
June	4.80	2.61	1.97	0.88	1.73
July	7.78	2.47	1.86	5.06	5.87
August	2.04	0.80	0.60	- -	- -
September	- -	- -	- -	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	15.64	6.69	5.04	5.95	7.60

TABLE 2-1B

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 1

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Alfalfa		Average Growing Season Dates: May 1 - September 1			
May	3.78	1.74	1.31	0.53	0.96
June	5.98	2.70	2.03	3.28	3.95
July	7.44	2.33	1.75	5.11	5.68
August	6.07	2.34	1.76	2.23	2.83
September	0.10	0.10	0.07	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	23.39	9.23	6.95	11.16	13.44
Crop: Grasses, Pasture		Average Growing Season Dates: May 1 - October 1			
May	3.57	1.68	1.27	0.38	0.80
June	5.56	2.71	2.04	2.84	3.51
July	7.04	2.05	1.54	4.98	5.49
August	5.92	2.46	1.85	3.46	4.06
September	3.19	1.15	0.87	0.54	0.84
October	0.04	0.03	- -	- -	- -
Season Total:	25.34	10.12	7.62	12.22	14.72
Crop: Small Grain, Spring		Average Growing Season Dates: May 5 - August 20			
May	1.65	1.22	0.92	- -	- -
June	5.12	2.67	2.01	1.22	2.34
July	7.55	2.60	1.95	4.95	5.60
August	3.30	1.46	1.10	0.34	0.70
September	- -	- -	- -	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	17.62	7.97	6.00	6.50	8.64
Crop: Soybeans		Average Growing Season Dates: May 20 - September 20			
May	0.37	0.36	0.27	- -	- -
June	2.35	2.11	1.59	- -	- -
July	5.22	1.99	1.50	1.97	3.08
August	7.33	2.60	1.96	4.72	5.37
September	2.68	0.74	0.55	0.43	0.62
October	- -	- -	- -	- -	- -
Season Total:	17.96	7.82	5.89	7.14	9.07

TABLE 2-1C

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 1

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Dry Beans		Average Growing Season Dates: June 10 - September 20			
May	- -	- -	- -	- -	- -
June	1.95	1.53	1.15	- -	- -
July	5.95	2.26	1.70	2.61	3.55
August	5.45	2.40	1.81	2.28	3.05
September	1.44	0.70	0.53	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	14.80	6.90	5.20	4.89	6.60
Crop: Tomatoes		Average Growing Season Dates: June 10 - September 1			
May	- -	- -	- -	- -	- -
June	1.73	1.46	1.10	- -	- -
July	5.73	2.22	1.67	2.29	3.20
August	5.38	2.38	1.79	1.54	2.13
September	0.07	0.03	0.02	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	12.94	6.10	4.60	3.83	5.34

TABLE 2-2A

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 2

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Potatoes		Average Growing Season Dates: May 5 - September 15			
May	1.10	1.06	0.82	- -	- -
June	3.50	2.81	2.18	- -	0.09
July	7.10	2.46	1.91	3.86	5.18
August	6.77	2.50	1.94	3.99	4.69
September	1.86	0.63	0.49	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	20.35	9.48	7.37	7.86	9.98
Crop: Sugar Beets		Average Growing Season Dates: May 10 - October 10			
May	1.14	1.08	0.84	- -	- -
June	3.49	2.80	2.18	- -	0.11
July	6.47	2.46	1.91	3.25	4.55
August	6.74	2.50	1.94	4.23	4.79
September	3.84	1.26	0.98	1.37	1.72
October	0.57	0.27	0.21	- -	- -
Season Total:	22.27	10.40	8.08	8.86	11.18
Crop: Corn, Grain		Average Growing Season Dates: May 10 - October 20			
May	1.46	1.28	0.99	- -	- -
June	4.09	2.77	2.15	- -	0.90
July	7.69	2.63	2.04	5.05	5.64
August	7.65	2.64	2.05	5.01	5.60
September	4.22	1.19	0.93	2.21	2.60
October	1.24	0.56	0.43	- -	- -
Season Total:	26.39	11.10	8.62	12.28	14.76
Crop: Alfalfa		Average Growing Season Dates: May 1 - September 15			
May	3.90	2.14	1.66	0.26	0.74
June	6.11	3.05	2.37	3.05	3.73
July	7.50	2.61	2.02	4.89	5.47
August	6.16	2.37	1.84	2.89	3.66
September	1.68	1.07	0.83	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	25.36	11.25	8.74	11.10	13.61

TABLE 2-2B

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 2

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Grasses, Pasture Average Growing Season Dates: May 1 - October 1					
May	3.70	2.14	1.67	0.05	0.53
June	5.69	3.19	2.47	2.50	3.21
July	7.11	2.47	1.92	4.64	5.19
August	6.02	2.31	1.79	3.71	4.22
September	3.39	1.20	0.93	0.69	0.97
October	0.05	0.04	0.03	- -	- -
Season Total:	25.98	11.37	8.84	11.60	14.14
Crop: Small Grain, Spring Average Growing Season Dates: April 25 - August 20					
April	0.09	0.09	0.07	- -	- -
May	2.75	1.97	1.53	- -	- -
June	6.20	3.37	2.62	2.11	3.33
July	7.77	2.79	2.17	4.71	5.60
August	2.63	1.40	1.09	- -	0.04
September	- -	- -	- -	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	19.30	9.64	7.49	6.82	8.97
Crop: Soybeans Average Growing Season Dates: May 15 - September 20					
May	0.58	0.57	0.44	- -	- -
June	2.53	2.40	1.87	- -	- -
July	5.61	2.38	1.85	1.87	3.06
August	7.46	2.60	2.02	4.85	5.43
September	2.56	0.84	0.65	0.22	0.41
October	- -	- -	- -	- -	- -
Season Total:	18.76	8.81	6.84	6.95	8.91
Crop: Dry Beans Average Growing Season Dates: June 1 - September 20					
May	- -	- -	- -	- -	- -
June	3.18	2.62	2.04	- -	- -
July	6.50	2.47	1.92	3.08	4.22
August	4.99	2.27	1.76	2.21	2.80
September	1.38	0.38	0.30	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	16.05	7.74	6.03	5.29	7.02

TABLE 2-2C

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 2

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Tomatoes		Average Growing Season Dates: June 1 - September 1			
May	- -	- -	- -	- -	- -
June	2.67	2.49	1.93	- -	- -
July	6.32	2.43	1.88	2.56	3.66
August	5.33	2.33	1.81	1.54	2.07
September	0.08	0.03	0.03	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	14.41	7.30	5.67	4.11	5.74
Crop: Green Peas		Average Growing Season Dates: May 10 - July 1			
May	1.75	1.34	1.04	- -	- -
June	5.35	3.07	2.39	- -	0.81
July	0.19	0.07	0.05	- -	- -
August	- -	- -	- -	- -	- -
September	- -	- -	- -	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	7.30	4.49	3.49	- -	0.81
Crop: Snap Beans		Average Growing Season Dates: June 1 - August 1			
May	- -	- -	- -	- -	- -
June	3.07	2.57	1.99	- -	- -
July	6.28	2.41	1.88	1.55	2.66
August	0.18	- -	- -	- -	- -
September	- -	- -	- -	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	9.54	4.99	3.87	1.55	2.66
Crop:		Average Growing Season Dates:			
May					
June					
July					
August					
September					
October					
Season Total:					

TABLE 2-3A

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 3

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Potatoes		Average Growing Season Dates: May 15 - September 10			
May	0.55	0.55	0.43	- -	- -
June	2.82	2.25	1.77	- -	- -
July	6.30	2.82	2.22	2.55	3.74
August	6.00	2.30	1.81	2.68	3.30
September	1.09	0.60	0.47	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	16.77	8.53	6.73	5.24	7.04
Crop: Corn, Silage		Average Growing Season Dates: May 20 - September 15			
May	0.62	0.60	0.47	- -	- -
June	3.40	2.40	1.89	- -	0.14
July	6.78	2.99	2.36	3.30	4.42
August	6.57	2.63	2.07	3.27	4.03
September	1.78	0.95	0.74	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	19.16	9.59	7.56	6.57	8.60
Crop: Corn, Sweet		Average Growing Season Dates: May 25 - September 1			
May	0.31	0.30	0.24	- -	- -
June	3.41	2.41	1.90	- -	0.08
July	6.94	3.01	2.37	3.44	4.56
August	5.96	2.59	2.04	1.92	2.48
September	0.11	0.06	0.04	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	16.76	8.39	6.61	5.36	7.14
Crop: Alfalfa		Average Growing Season Dates: May 5 - September 1			
May	2.94	2.12	1.67	- -	- -
June	5.56	2.70	2.13	2.18	3.20
July	6.74	2.98	2.35	3.75	4.38
August	5.43	2.45	1.93	1.47	2.01
September	0.09	0.09	0.07	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	20.78	10.37	8.17	7.41	9.60

TABLE 2-3B

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 3

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Grasses, Pasture		Average Growing Season Dates: May 10 - September 15			
May	2.24	1.94	1.53	- -	- -
June	5.16	2.61	2.06	1.34	2.31
July	6.36	2.85	2.25	3.51	4.11
August	5.29	2.38	1.88	1.54	2.33
September	1.48	1.33	1.05	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	20.55	11.14	8.78	6.40	8.76
Crop: Small Grain, Spring		Average Growing Season Dates: May 5 - August 20			
May	1.57	1.34	1.05	- -	- -
June	5.06	2.59	2.04	1.21	2.05
July	7.24	3.03	2.39	4.21	4.85
August	3.19	1.58	1.24	0.11	0.45
September	- -	- -	- -	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	17.06	8.55	6.74	5.53	7.35
Crop: Small Vegetables		Average Growing Season Dates: June 1 - August 20			
May	- -	- -	- -	- -	- -
June	3.24	2.31	1.82	2.42	3.83
July	6.28	2.81	2.21	- -	- -
August	2.55	1.52	1.20	- -	- -
September	- -	- -	- -	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	12.08	6.66	5.25	2.42	3.83
Crop:		Average Growing Season Dates:			
May					
June					
July					
August					
September					
October					
Season Total:					

TABLE 2-4A

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 4

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Potatoes		Average Growing Season Dates: April 25 - September 1			
April	0.07	0.07	0.05	- -	- -
May	1.39	1.39	1.10	- -	- -
June	4.15	2.82	2.22	- -	0.73
July	7.08	2.46	1.94	4.44	5.13
August	5.98	2.79	2.20	1.75	2.35
September	0.11	0.05	0.04	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	18.80	9.60	7.58	6.19	8.22
Crop: Corn, Grain		Average Growing Season Dates: May 10 - September 20			
April	- -	- -	- -	- -	- -
May	1.32	1.32	1.04	- -	- -
June	4.18	2.84	2.24	- -	0.71
July	7.69	2.73	2.15	4.80	5.53
August	6.56	2.89	2.28	3.38	4.22
September	2.29	1.07	0.84	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	22.06	10.87	8.58	8.19	10.47
Crop: Corn, Sweet		Average Growing Season Dates: May 5 - September 1			
April	- -	- -	- -	- -	- -
May	1.65	1.65	1.30	- -	- -
June	4.68	3.11	2.45	0.07	1.07
July	7.60	2.71	2.14	4.89	5.46
August	6.28	2.79	2.20	2.05	2.64
September	0.11	0.05	0.04	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	20.34	10.32	8.15	7.01	9.19

TABLE 2-4B

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 4

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Alfalfa		Average Growing Season Dates: May 1 - September 1			
April	- -	- -	- -	- -	- -
May	3.60	2.42	1.91	- -	0.18
June	5.79	3.26	2.57	2.21	3.21
July	7.04	2.44	1.92	4.60	5.11
August	5.71	2.78	2.20	1.42	2.03
September	0.10	0.10	0.08	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	22.26	11.02	8.70	8.23	10.55
Crop: Grasses, Pasture		Average Growing Season Dates: May 1 - September 20			
April	- -	- -	- -	- -	- -
May	3.43	2.40	1.89	- -	0.04
June	5.43	3.14	2.48	1.82	2.95
July	6.73	2.59	2.04	4.13	4.68
August	5.62	2.77	2.19	2.11	2.98
September	2.14	1.37	1.08	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	23.36	12.29	9.70	8.07	10.66
Crop: Grain, Small		Average Growing Season Dates: April 20 - September 20			
April	0.22	0.20	0.16	- -	- -
May	2.96	2.22	1.75	- -	- -
June	6.55	3.29	2.60	2.52	3.72
July	7.53	2.61	2.06	3.92	4.78
August	1.98	1.48	1.17	- -	- -
September	- -	- -	- -	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	19.24	9.83	7.76	6.44	8.50

TABLE 2-4C

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 4

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Soybeans		Average Growing Season Dates: May 15 - September 20			
April	- -	- -	- -	- -	- -
May	0.56	0.56	0.44	- -	- -
June	2.54	2.44	1.93	- -	- -
July	5.59	2.44	1.93	1.74	2.89
August	7.33	2.97	2.35	4.27	4.97
September	2.56	1.13	0.89	- -	0.16
October	- -	- -	- -	- -	- -
Season Total:	18.60	9.58	7.56	6.02	8.04
Crop: Vegetables, Small		Average Growing Season Dates: May 10 - September 1			
April	- -	- -	- -	- -	- -
May	1.11	1.11	0.88	- -	- -
June	4.33	2.94	2.32	- -	0.74
July	6.26	2.44	1.93	3.71	4.33
August	4.07	2.45	1.93	0.13	0.65
September	0.05	0.04	0.03	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	15.84	9.00	7.10	3.84	5.73
Crop: Dry Beans		Average Growing Season Dates: June 1 - September 20			
April	- -	- -	- -	- -	- -
May	- -	- -	- -	- -	- -
June	3.05	2.56	2.02	- -	- -
July	6.17	2.40	1.89	2.75	3.80
August	4.68	2.67	2.11	1.32	1.99
September	1.31	0.49	0.38	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	15.22	8.13	6.42	4.08	5.79

TABLE 2-4D

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 4

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Tomatoes		Average Growing Season Dates: June 1 - September 1			
April	- -	- -	- -	- -	- -
May	- -	- -	- -	- -	- -
June	2.68	2.54	2.00	- -	- -
July	6.28	2.45	1.94	2.46	3.52
August	5.24	2.66	2.10	1.10	1.67
September	0.08	0.05	0.04	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	14.29	7.72	6.09	3.57	5.19
Crop:		Average Growing Season Dates:			
April					
May					
June					
July					
August					
September					
October					
Season Total:					
Crop:		Average Growing Season Dates:			
April					
May					
June					
July					
August					
September					
October					
Season Total:					

TABLE 2-5A

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 5

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Potatoes		Average Growing Season Dates: April 25 - September 20			
April	0.08	0.08	0.06	- -	- -
May	1.49	1.46	1.13	- -	- -
June	4.04	2.73	2.11	- -	0.80
July	7.31	2.23	1.73	4.91	5.58
August	6.90	2.19	1.70	4.70	5.20
September	2.71	0.98	0.76	0.22	0.45
October	- -	- -	- -	- -	- -
Season Total:	22.56	9.71	7.51	9.85	12.04
Crop: Corn, Grain		Average Growing Season Dates: May 5 - October 10			
April	- -	- -	- -	- -	- -
May	1.86	1.63	1.26	- -	- -
June	4.47	2.91	2.25	0.30	1.32
July	8.06	2.20	1.70	5.86	6.35
August	7.50	2.27	1.75	5.23	5.74
September	4.28	1.61	1.24	1.62	2.04
October	0.68	0.22	0.17	- -	- -
Season Total:	26.87	10.85	8.40	13.02	15.47
Crop: Corn, Sweet		Average Growing Season Dates: May 15 - September 1			
April	- -	- -	- -	- -	- -
May	1.04	0.96	0.74	- -	- -
June	4.40	2.88	2.23	0.10	0.97
July	7.89	2.43	1.88	5.46	6.01
August	6.72	2.19	1.69	3.11	3.62
September	0.13	0.04	0.03	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	20.20	8.52	6.59	8.68	10.61

TABLE 2-5B

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 5

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Alfalfa		Average Growing Season Dates: April 25 - September 10			
April	0.29	0.29	0.22	- -	- -
May	4.16	2.20	1.70	0.46	1.02
June	6.33	3.13	2.43	3.19	3.90
July	7.61	2.36	1.83	5.24	5.77
August	6.26	2.07	1.60	2.78	3.50
September	1.22	1.12	0.87	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	25.89	11.20	8.67	11.68	14.22
Crop: Grass, Pasture		Average Growing Season Dates: April 15 - October 10			
April	0.90	0.90	0.69	- -	- -
May	4.08	2.15	1.66	0.42	1.11
June	6.10	3.03	2.34	3.07	3.76
July	7.46	2.31	1.78	5.15	5.67
August	6.33	2.10	1.63	4.23	4.70
September	3.80	1.74	1.34	0.73	1.22
October	0.61	0.44	0.34	- -	- -
Season Total:	29.32	12.69	9.82	13.62	16.49
Crop: Grain, Small Spring		Average Growing Season Dates: April 15 - August 15			
April	0.46	0.39	0.30	- -	- -
May	3.72	2.22	1.72	0.07	0.66
June	7.46	3.39	2.63	4.07	4.83
July	7.61	2.42	1.87	4.27	5.02
August	1.44	0.86	0.66	- -	- -
September	- -	- -	- -	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	20.69	9.31	7.20	8.41	10.51

TABLE 2-5C

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 5

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Soybeans		Average Growing Season Dates: May 15 - October 1			
April	- -	- -	- -	- -	- -
May	0.60	0.60	0.46	- -	- -
June	2.65	2.41	1.86	- -	- -
July	5.75	2.17	1.68	2.32	3.50
August	7.66	2.31	1.78	5.35	5.87
September	3.99	1.76	1.36	0.76	1.16
October	- -	- -	- -	- -	- -
Season Total:	20.69	9.27	7.17	8.45	10.55
Crop: Small Vegetables		Average Growing Season Dates: May 5 - September 15			
April	- -	- -	- -	- -	- -
May	1.24	1.21	0.93	- -	- -
June	4.66	2.95	2.28	0.24	1.18
July	6.98	2.30	1.78	4.67	5.19
August	5.49	2.05	1.59	2.34	2.97
September	1.14	0.73	0.56	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	19.52	9.25	7.16	7.26	9.35
Crop: Green Peas		Average Growing Season Dates: May 1 - July 1			
April	- -	- -	- -	- -	- -
May	2.81	2.07	1.60	- -	- -
June	5.58	3.07	2.37	0.38	1.56
July	0.19	0.06	0.05	- -	- -
August	- -	- -	- -	- -	- -
September	- -	- -	- -	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	8.60	5.21	4.03	0.38	1.56

TABLE 2-5D

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 5

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Tomatoes		Average Growing Season Dates: June 1 - September 1			
April	- -	- -	- -	- -	- -
May	- -	- -	- -	- -	- -
June	2.80	2.48	1.92	- -	- -
July	6.49	2.20	1.70	3.10	4.17
August	5.49	2.05	1.59	1.97	2.45
September	- -	- -	0.04	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	14.89	6.80	5.26	5.08	6.62
Crop: Sorghum		Average Growing Season Dates: May 10 - September 20			
April	- -	- -	- -	- -	- -
May	1.13	1.11	0.86	- -	- -
June	5.04	2.90	2.24	0.66	1.57
July	8.39	2.41	1.87	5.97	6.52
August	5.81	2.10	1.62	2.92	3.64
September	1.80	1.08	0.84	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	22.19	9.62	7.44	9.56	11.74
Crop:		Average Growing Season Dates:			
April					
May					
June					
July					
August					
September					
October					
Season Total:					

TABLE 2-6A

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 6

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Potatoes		Average Growing Season Dates: April 15 - September 20			
April	0.27	0.27	0.21	- -	- -
May	1.64	1.64	1.31	- -	- -
June	4.26	3.11	2.49	- -	0.65
July	6.89	2.60	2.08	3.92	4.80
August	6.34	2.53	2.02	3.45	4.23
September	2.50	1.34	1.07	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	21.91	11.52	9.21	7.38	9.70
Crop: Corn, Grain		Average Growing Season Dates: April 25 - October 20			
April	0.15	0.15	0.12	- -	- -
May	2.28	2.10	1.68	- -	- -
June	4.61	3.21	2.57	0.07	1.17
July	7.67	2.72	2.18	4.94	5.49
August	7.14	2.52	2.02	4.61	5.11
September	4.18	1.89	1.51	1.47	1.98
October	1.33	0.65	0.51	- -	- -
Season Total:	27.39	13.28	10.62	11.10	13.77
Crop: Corn, Sweet		Average Growing Season Dates: May 10 - September 15			
April	- -	- -	- -	- -	- -
May	1.37	1.36	1.08	- -	- -
June	4.24	3.11	2.48	- -	0.54
July	7.37	2.62	2.10	4.39	5.27
August	6.54	2.63	2.10	3.35	4.08
September	1.97	1.02	0.82	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	21.51	10.76	8.60	7.74	9.90

TABLE 2-6B

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 6

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Alfalfa		Average Growing Season Dates: April 20 - September 15			
April	0.58	0.58	0.46	- -	- -
May	4.07	2.44	1.95	0.12	0.73
June	6.14	3.37	2.69	2.76	3.44
July	7.15	2.51	2.01	4.64	5.14
August	5.92	2.61	2.08	1.95	2.79
September	1.73	1.59	1.27	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	25.62	13.13	10.49	9.48	12.12
Crop: Pasture Grasses		Average Growing Season Dates: April 10 - October 10			
April	1.18	1.09	0.87	- -	- -
May	3.94	2.51	2.01	0.02	0.75
June	5.85	3.36	2.69	2.49	3.16
July	6.94	2.60	2.08	3.31	3.84
August	5.93	2.61	2.08	3.31	3.84
September	3.57	1.97	1.58	0.15	0.65
October	0.57	0.52	0.41	- -	- -
Season Total:	28.03	14.70	11.75	10.32	13.28
Crop: Grain, Small		Average Growing Season Dates: April 10 - August 15			
April	0.72	0.61	0.48	- -	- -
May	4.23	2.41	1.92	0.43	1.05
June	7.76	3.88	3.10	3.88	4.66
July	6.86	2.59	2.07	2.92	3.59
August	0.90	0.75	0.60	- -	- -
September	- -	- -	- -	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	20.47	10.25	8.19	7.23	9.30

TABLE 2-6C

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

CLIMATIC AREA 6

Carryover Moisture = 3.0 inches Net Irrigation Application = 3.0 inches

Month	Consumptive Use (Inches)	Effective Rainfall (In.)		Net Irrigation (In.)	
		Normal Year	Dry Year	Normal Year	Dry Year
Crop: Soybeans		Average Growing Season Dates: May 10 - October 1			
April	- -	- -	- -	- -	- -
May	0.83	0.77	0.61	- -	- -
June	2.82	2.80	2.24	- -	- -
July	5.91	2.45	1.96	2.03	3.25
August	7.40	2.80	2.24	4.38	5.16
September	3.18	1.90	1.52	- -	0.16
October	- -	- -	- -	- -	- -
Season Total:	20.14	10.72	8.57	6.41	8.57
Crop: Small Vegetables		Average Growing Season Dates: May 1 - September 1			
April	- -	- -	- -	- -	- -
May	1.89	1.89	1.51	- -	- -
June	4.73	3.24	2.59	- -	1.02
July	6.14	2.38	1.90	3.75	4.23
August	4.01	2.12	1.69	0.39	0.83
September	0.05	0.04	0.03	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	16.84	9.69	7.74	4.15	6.10
Crop: Tomatoes		Average Growing Season Dates: May 20 - September 10			
April	- -	- -	- -	- -	- -
May	0.65	0.65	0.52	- -	- -
June	3.12	2.86	2.29	- -	- -
July	6.49	2.53	2.02	2.71	3.93
August	5.59	2.53	2.02	1.87	2.51
September	0.95	0.64	0.51	- -	- -
October	- -	- -	- -	- -	- -
Season Total:	16.82	9.23	7.38	4.58	6.44

Example of finding monthly and seasonal irrigation requirements when carryover moisture and net application depths are different than 3.0 inches. In Minnesota, the soil profile will usually be at field capacity at the beginning of the growing season. Therefore, the carryover moisture will be equivalent to the net irrigation application.

Given:
1) Climatic Area 2.
2) Crop - Potatoes.
3) Carryover moisture is 1.0 inch.
4) Net irrigation application is 1.0 inch.

Find:
1) Eighty percent chance (dry year) irrigation requirements by month and for the season.

Solution:
1) Refer to Table 2-2A for potatoes.
2) Find adjustment factor for 1.0 inch application (Page 2-2, Chapter 2) is 0.77. Multiply the factor times the monthly effective rainfall from Table 2-2A.
3) Set up a table as follows:

Month	Consumptive Use	80% Effective Rainfall from Table 2-2A	80% Effective Rainfall Adjusted	Adjusted Net Irrigation
May	1.10	0.82	0.63	--- 1/
June	3.50	2.18	1.68	1.29 2/
July	7.10	1.91	1.47	5.63
August	6.77	1.94	1.49	5.28
September	1.86	0.49	0.38	1.48
Season Total:	20.35	7.37	5.65	13.68 3/

1/ Uses part of the carryover moisture: (1.10 - 0.63 = 0.47 inches used from carryover). This leaves 1.00 - 0.47 = 0.53 inches to be used in June.

2/ 3.50 - 1.68 = 1.82 inches. Carryover moisture will supply 0.53 inches of this. 1.82 - 0.53 = 1.29 inches.

3/ Summation of monthly total will be the same as: 20.35 - (5.65 + 1.00) = 13.7, that is; seasonal consumptive use less the moisture available as seasonal effective rainfall and carryover moisture is the seasonal irrigation requirement.

Table 2-7

PEAK CONSUMPTIVE USE VALUES (INCHES/DAY)

Climatic Area	Net Application (In.)		Potatoes	Sugar Beets	Corn, Grain	Corn, Sweet	Corn, Silage	Alfalfa	Grass, Pasture	Grain, Small	Soybeans	Dry Beans	Tomatoes	Peas, Green	Beans, Snap	Small Vegetable	Sorghum, Grain
	1.0		0.27	0.27	0.30	0.31	- - -	0.30	0.28	0.30	0.30	0.24	0.23	- - -	- - -	- - -	- - -
1	2.0		0.26	0.26	0.28	0.30	- - -	0.28	0.27	0.29	0.28	0.23	0.22	- - -	- - -	- - -	- - -
	3.0		0.25	0.25	0.27	0.29	- - -	0.27	0.26	0.28	0.27	0.22	0.21	- - -	- - -	- - -	- - -
	1.0		0.28	0.27	0.31	- - -	- - -	0.31	0.28	0.31	0.31	0.26	0.25	0.21	0.25	- - -	- - -
2	2.0		0.27	0.26	0.30	- - -	- - -	0.29	0.27	0.30	0.29	0.25	0.24	0.20	0.24	- - -	- - -
	3.0		0.26	0.25	0.29	- - -	- - -	0.28	0.26	0.29	0.28	0.24	0.23	0.19	0.23	- - -	- - -
	1.0		0.25	- - -	- - -	0.27	0.27	0.27	0.25	0.29	- - -	- - -	- - -	- - -	- - -	0.25	- - -
3	2.0		0.24	- - -	- - -	0.26	0.26	0.26	0.24	0.28	- - -	- - -	- - -	- - -	- - -	0.24	- - -
	3.0		0.23	- - -	- - -	0.25	0.25	0.25	0.23	0.27	- - -	- - -	- - -	- - -	- - -	0.23	- - -
	1.0		0.29	- - -	0.31	0.31	- - -	0.28	0.27	0.31	0.29	0.25	0.25	- - -	- - -	0.25	- - -
4	2.0		0.27	- - -	0.30	0.29	- - -	0.27	0.26	0.29	0.28	0.24	0.24	- - -	- - -	0.24	- - -
	3.0		0.26	- - -	0.29	0.28	- - -	0.26	0.25	0.28	0.27	0.23	0.23	- - -	- - -	0.23	- - -
	1.0		0.30	- - -	0.32	0.31	- - -	0.30	0.31	0.31	0.32	- - -	0.26	0.22	- - -	0.28	0.35
5	2.0		0.28	- - -	0.31	0.30	- - -	0.29	0.29	0.29	0.30	- - -	0.25	0.20	- - -	0.27	0.33
	3.0		0.27	- - -	0.30	0.29	- - -	0.28	0.28	0.28	0.29	- - -	0.24	0.20	- - -	0.26	0.32
	1.0		0.28	- - -	0.31	0.29	- - -	0.29	0.28	0.31	0.30	- - -	0.26	- - -	- - -	0.25	- - -
6	2.0		0.27	- - -	0.30	0.28	- - -	0.27	0.27	0.30	0.28	- - -	0.25	- - -	- - -	0.24	- - -
	3.0		0.26	- - -	0.29	0.27	- - -	0.26	0.26	0.29	0.27	- - -	0.24	- - -	- - -	0.23	- - -

Crop Rooting Depths and Irrigation Depths

For most crops, the maximum depth of root penetration is comparable to the height of the plant above ground. While not always true, it is a relatively good guide. The most notable exception to this is alfalfa which is a perennial. Grasses, while perennial, are fairly shallow rooted. Where soil conditions are such that there is no restrictive zone to limit root growth, the maximum rooting depths for certain crops are shown in Table 2-8. Moisture extraction patterns for most crops indicate that if adequate water is available, about 70 percent of the water requirement is taken from the top 50 percent of the root depth. Therefore, in an irrigation management program, it is more practical to use an irrigation depth less than the total rooting depth to compute irrigation amounts to add to the soil profile. Irrigation depths for commonly irrigated crops are listed in Table 2-8.

Table 2-8

Crop	Rooting Depth (feet)	Irrigation Depth (feet)
Alfalfa	3-5	4.0
Sugar Beets	2-4	3.0
Corn (Field & Sweet)	4-6	3.0
Soybeans	2-3	2.0
Field Beans--Snap, Pinto, etc.	2-3	2.0
Small Grain	3-4	2.0
Grass	2-3	2.0
Potatoes	2-3	2.0
Small Vegetables	2-3	2.0
Grain Sorghum		3.0
Green Peas	2-3	2.0
Tomatoes	2-3	2.5
Turf, sod, strawberries, flowers	1-2	1.0

Crop Production, Stress and Critical Growth Period

When crop stress from moisture shortage is eliminated by proper and timely irrigation, other factors become inhibitors to production. These factors include poor soil structure and tilth, low fertility, poor stands, weeds, insects and diseases. Much of the water applied through irrigation may be wasted unless sound farming practices are followed.

Soil structure and tilth must be favorable in order to have good aeration, good initial water intake, and good soil permeability. Good soil tilth prevents runoff and water waste. Tilth and structure can be maintained or improved by avoiding cultivation of wet fields, addition of manure or plowing under green manure crops, using grass and legumes in rotation, stubble mulch farming, and minimum tillage. On irrigated pastures, cattle should be excluded until surface soil is dry after irrigation.

Low fertility or an imbalance of nutrients are often the limiting factors on irrigated land. The well-fed plant uses water much more efficiently than a plant that is starved or lacking in some nutrient elements. Total water use by a healthy, well-fed plant is greater than for a plant deprived of plant food, but the production per unit of water is much greater for the well-fed plant. Fertility problems should be corrected by the application of barnyard manure and commercial fertilizer. Soil tests, observations, and field experiences help determine the type and amount of fertilizers to use. Crop quality may be more important than crop production. Quality can be greatly improved by proper fertility.

Adequate moisture and fertility, and good soil physical conditions will not insure high production unless the irrigation farmer controls pests, uses high quality seed of adapted varieties, and uses timely operations. Weeds, insects, and diseases may be a greater problem on irrigated than on dryland. Crops and varieties should be selected to fit the soil and irrigation system. Plant population should be increased in most cases to take advantage of water added by irrigation.

For maximum production and most efficient use of water, plants must have ample moisture throughout the growing season. This is most important during critical periods of growth and development. Although plants indicate moisture stress by various symptoms, yields will usually be reduced by the time the plant shows stress. Time of irrigation should be determined by examination of the soil for moisture content. The feel and appearance of the soil at various moisture contents are given in Chapter 7. Symptoms of serious moisture stress, critical water requirement periods, and other irrigation considerations are listed on Table 2-9.

TABLE 2-9

MOISTURE STRESS SYMPTOMS AND

CRITICAL GROWTH PERIOD FOR IRRIGATED CROPS

CROP	SERIOUS MOISTURE STRESS	CRITICAL GROWTH PERIOD	OTHER CONSIDERATIONS
Alfalfa	Bluish green color, then wilting.	Seedling and immediately after cuttings.	Soil kept moist in upper 5 feet. Avoid over-irrigation. Fall irrigation is desirable.
Corn	Leaf curl by 10:00 a.m.	Tasseling stage until grain becomes firm.	Sensitive to over-irrigation from seedling stage to 3 ft. in height. Needs adequate moisture from germination to dent stage.
Sorghum	Leaf curl by 10:00 a.m.	Boot, bloom, and milk-dough stages.	Need adequate moisture--germination through dough stage. Reduced yields when moisture is short during heading and seed development.
Grass Pasture	Dull green color, then wilting.	Seedling stage, for seed production boot to head formation.	Late fall irrigation is necessary. Frequent, light applications. Irrigate at end of grazing period in a rotation system.
Sugar Beets	Leaves wilting during mid-day.	From seedling stage through root enlargement.	Shallow, frequent irrigation. Avoid over-irrigation. Late fall irrigation lowers amount of sugar.
Small Grain	Dull green color, then firing of lower leaves.	Boot, bloom and early head stage.	Fall grain, irrigate before planting to top 4 feet. Last irrigation at milk stage. Spring small grain as a nurse crop, irrigate for needs of grass seedlings.
Dry Beans & Soybeans	Dull color, then wilting.	Early bloom, seed forming.	Very sensitive to over-irrigation. Last irrigation at time of first set of pod maturity.
Potatoes	Darkening of leaves, then wilting.	Tuber swelling period.	Water should not stand around tubers. Do not over-irrigate. Lower tuber quality if plants go into serious moisture stress. Last irrigation 3 to 4 weeks before harvest.

Proper irrigation should not be based on moisture stress signals from the crop. If irrigation is delayed until moisture stress symptoms are apparent, it can be assumed that there will be some reduction in yield. Proper irrigation is based on soil moisture condition.

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SOILS

Introduction

A variety of soils occur in Minnesota which range in many important properties such as texture, organic matter content, nutrient content, slope, natural drainage, available water capacity, bulk density, and intake rate.

In considering the adaptability of soils for irrigation, the more important properties to consider are available water capacity, intake rate, slope and wetness. A brief discussion of each of these properties follow.

The available water capacity (AWC) of a soil is a measure of its capacity to make water available for plant growth. The AWC is the amount of water held between field capacity and the permanent wilting point. AWC of a soil is primarily related to the soil texture, organic matter content, and bulk density. A formula for the computation of available water capacity is:

$$AWC = \frac{d_b \times T \times P_w}{d_w \times 100}$$

Where:

AWC = Available water capacity in inches

d_b = Bulk density

$$\frac{\text{(Wt. of ovendry soil sample in grams)}}{\text{(Field Volume of sample in C.C.)}}$$

T = Thickness of soil horizon under consideration in inches

P_w = Moisture content between field capacity and wilting point in percentage by weight

d_w = Density of water taken as 1.

Table 3-1

Available Water Capacity

As A Function of Organic Matter Content and Soil Texture

		High Organic Matter	Low Organic Matter
1.	Coarse sand and gravel.	.04 - .06 1/	.02 - .04
2.	Sand.	.07 - .09	.05 - .07
3.	Fine sand, loamy coarse sand, loamy sand, loamy fine sand	.10 - .12	.08 - .10
4.	Gravelly sandy loams and gravelly loams	.08 - .12	.05 - .08
5.	Sandy loam, coarse sandy loam	.13 - .15	.11 - .13
6.	Fine sandy loam	.16 - .18	.14 - .16

1/ AWC expressed in inches per inch

The ranges of available water capacities are the adjusted water retention difference between 1/3-bar and 15-bar tension for the medium and fine textured soils, and between 1/10-bar and 15-bar for the moderately coarse and coarse textures.

Table 3-1 gives AWC values for different soil texture classes with two different levels of organic matter content. Table 3-2 shows classes of AWC for soils. In regard to particle size, not only is the particle size of each horizon important in determining its capacity, but also of importance is the arrangement in the soil profile of horizons with different particle size. For example, a soil with loam A and B horizons and a sandy C horizon may have higher AWC than indicated from Table 3-1. This is because a certain head is required for water to move into the C horizon because of the lower moisture tensions in the sandy material. That head is at a water content somewhat higher than field capacity. This property has to be measured in the field, and unfortunately, very few such measurements have been made.

Intake Rate is a measure of a soils capacity to absorb irrigation water from the surface and move it into and through the soil profile. It is an expression of several factors, including infiltration and percolation.

Infiltration is the downward flow of water from the surface through the soil. Water enters the soil through pores, cracks, worm and decayed root holes, and cavities introduced by tillage. Surface sealing or crusting will restrict infiltration.

Percolation is the movement of water through the soil profile. In order for irrigation water to be effective in replenishing the soils water supply, it must be able to move through the profile, or percolate, to a predetermined irrigation depth. The percolation rate is governed by the permeability of the soil or its hydraulic conductivity. Both terms are used to describe the ease with which soil transmits water and air. The relative permeability of soils is described in general terms as rapid, moderate, and slow. Table 3-3 shows the permeability classes used for soils.

The amount of moisture already in the soil greatly influences the rate at which water enters the soil. The soil takes in and absorbs irrigation water rapidly when water is first applied to the field surface. As the irrigation application continues, the surface soil gradually becomes saturated and the intake rate decreases until it reaches a nearly constant value.

The intake rate of any soil is limited by any restriction to the flow of water into or through the soil profile. The soil layer with the lowest transmission rate, either at the surface or below it, usually determines intake rate. The most important general factors that influence intake rate are the physical properties of the soil and, in sprinkler irrigation, the plant cover. But for any given soil, other factors may affect the intake rate.

Since so many factors affect water intake, it is not surprising that it varies so much among soils. Furthermore, the intake characteristics of a given field vary from place to place, from irrigation to irrigation, and from season to season. The intake characteristics that must be considered in sprinkler-irrigation design differ from those for surface methods.

Slope is an important factor in determining runoff and subsequently, intake rates. Refer to Table 3-4 for slope categories and the recommended sprinkler application rates for various intake families.

Wetness or the presence of a saturated zone (water table) is a prime factor in determining soils adaptability for irrigation. If a saturated zone is at shallow depths, a hazard always exists that heavy rains can raise the saturated zone to depths shallow enough to slow or inhibit plant growth. Thus, soils with wetness limitations are placed in groups separate from other similar soils except for that feature.

Table 3-2. Classes for Available Water Capacity for Soils.

Inches water in 60" depth of soil or to a limiting layer whichever is shallower	Class name
0-3	very low
3-6	low
6-9	moderate
9-12	high
greater than 12	very high

Table 3-3. Permeability Classes Used for Soils.

Rate (inches/hour)	Class name
less than 0.06	very slow
0.06-0.2	slow
0.2-0.6	moderately slow
0.6-2.0	moderate
2.0-6.0	moderately rapid
6.0-20.0	rapid
greater than 20.0	very rapid

Soil Groups for Irrigation Planning

To facilitate general planning for irrigation, most of the soil series in Minnesota are placed into groups. (A few soil series are excluded because of certain properties such as steep slope, rockiness or stoniness that essentially preclude their being irrigated.)

Soil groups 2 through 12 are generally considered as suitable for irrigation. Soil group 1 is generally considered as unsuitable because of its extremely low available water holding capacity and high susceptibility for nutrient loss through leaching. Soil groups with the "W" suffix are generally not irrigable because of a wetness limitation. Soil groups 13 through 25 have favorable soil properties for dry land farming and irrigation is generally not needed except on a supplemental basis.

The soil series within each group have somewhat similar characteristics in regard to texture, profile, available water capacity, intake rate, and soil drainage (presence or absence of saturated zones with shallow depths). Thus, an individual group can be used as a unit in irrigation planning. The representative profile for a group and the associated available water capacity are typical for the soil group, however, when planning an irrigation installation on a given site, the properties of the specific soil series occurring there will need to be considered. Its AWC, for example, can be computed using data in Table 3-1. In fact, some soil series have such a wide range in properties important to irrigation that certain phases may need to be recognized for on-site planning for irrigation. Further, the fact needs to be realized that delineations on standard soil maps at scale of 1:15,840 or smaller may have inclusions of other kinds of soil (some of which may have properties rather contrasting from the soil whose name is used for the mapping unit) that are as large as 2 to 3 acres.

Irrigation Intake Families

Each kind of soil has its own intake characteristics, but the differences between some soils are so minor that for practical purposes they can be considered together. These groups, called Intake Families, have been assigned numbers such as 0.1, 0.3, 0.5, 1.0, 1.5, 2.0 and 3.0, which are merely designations that approximate the basic intake rate for soils in those families. The guide lists, alphabetically, the name of irrigable soils in Minnesota. This listing shows the Irrigation Group number has then been assigned to an Intake Family. The Intake Family designation is used in conjunction with the net irrigation application to find the maximum allowable sprinkler application rate from Table 3-4. Table 3-4 is not necessarily the optimum rate that should be used for design.

Whether or not a center pivot system is suitable for use on a particular soil depends primarily on the intake rate of the soil, its slope, and cover or amount of residue on the surface. Generally, Intake Families 0.1 and 0.3 are not recommended to be irrigated by center pivot systems, volume guns, or other high application rate systems because of the low intake rate of application normally produced by these systems. Wheel ruts and tracks will also develop in these soils. Figure 3-3 may be used as a guide to the suitability of center pivot systems on various combinations of soil and slope.

Maximum Sprinkler Application Rate - P - (Inches/Hour)

For close growing crops or row crops with 4,000 pounds or more residue on the surface.

Intake Family	Slopes	Net Irrigation Application - F - (Inches)								
		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
4	2% or less	No Restrictions Within Practical Design Criteria.								
	2 to 5									
	5 to 12									
3	2% or less									
	2 to 5									
	5 to 12						1.70	1.65	1.60	1.55
2	2% or less						1.70	1.65	1.60	1.55
	2 to 5						1.15	1.10	1.05	1.05
	5 to 12	1.55	1.40	1.30	1.25	1.20				
1.5	2% or less						1.70	1.65	1.60	1.55
	2 to 5		1.60	1.50	1.40	1.35	1.30	1.25	1.20	1.15
	5 to 12	1.15	1.05	1.00	0.90	0.90	0.85	0.80	0.80	0.75
1.0	2% or less	1.60	1.45	1.30	1.25	1.20	1.15	1.10	1.05	1.00
	2 to 5	1.20	1.10	1.00	0.95	0.90	0.85	0.85	0.80	0.75
	5 to 12	0.80	0.75	0.65	0.60	0.60	0.55	0.55	0.50	0.50
0.5	2% or less	0.80	0.70	0.65	0.60	0.55	0.55	0.50	0.50	0.45
	2 to 5	0.60	0.55	0.50	0.45	0.40	0.40	0.35	0.35	0.30
	5 to 12	0.40	0.35	0.30	0.30	0.25	0.25	0.25	0.25	0.20
0.3	2% or less	0.50	0.40	0.35	0.35	0.30	0.30	0.30	0.25	0.25
	2 to 5	0.40	0.30	0.25	0.25	0.25	0.20	0.20	0.20	0.20
	5 to 12	0.25	0.20	0.20	0.20	--	--	--	--	--

The basic value for "P" was calculated assuming excellent cover and flat slopes ($< 2\%$). The following equation was used: $P = 60\ ab\ \left(\frac{F}{a}\right)^{\frac{b-1}{b}}$ The values for "a" and "b" were taken from Chapter 4, National Engineering Handbook, Section 15.

For clean tilled crops:
With 3,000 to 4,000 lbs. use 90% of above.
With 2,000 to 3,000 lbs. use 80% of above.
With 1,000 to 2,000 lbs. use 70% of above.
With less than 1,000 lbs. use 60% of above.

Table 3-4

ALPHABETICAL LIST OF SOILS AND THEIR IRRIGATION GROUP NUMBER

Soil	Irrigation Group No.
Aastad	24
Aazdahl	24
Aazdahl-Hamerly-Parnell complex	24
Adolph, depressional	24W
Adolph, level	24W
Adrian	26W
Afton	25W
Ahmeek	18
Alcester	20
Allendale	4W
Almena	19
Alvin	6
Alstad	21
Amery	6
Ames	15W
Ankeny	6
Anoka	10
Antigo	19
Arcola	25
Arenzville	21
Arveson	3W
Arveson, depressional	3W
Arvilla	8
Athelwold	19
Auburndale	24W
Augsburg	15W
Augsburg, depressional	15W
Barbert	25W
Barnes	15
Baroda	25W
Barrington	20
Barrows	15W
Baudette	21
Bearden sil	20
Bearden sicl	24
Beauford	25
Becker	6
Bellechester	2
Beltrami	16
Bena	3
Benoit	12W
Beotia	20
Bergland	25W
Bertrand	21
Beseman	26W
Billet	6
Biscay	12W
Biscay, depressional	12W
Bixby	13
Blackhoof & Mahtowa soils	24W
Blomford	4W
Blooming	22
Blue Earth	24W
Bluffton	24W
Bold	21
Bold-Truman complex	21
Boone	3*(s)
Boots	26W
Borofolists	26W
Borosaprists, shallow (to rock)	26W
Borup	15W
Borup, depressional	15W
Braham	4
Brainerd	18
Bremer	24W
Brickton	25W
Brill	19
Brookings	24
Brophy	26W
Brownton	24W
Burkhardt	8
Burnsville	8
Buse	16
Calco	24W
Campia	21
Canisteo l or cl	24W
Carlos	26W
Caron	26W
Cashel	25W
Cathro	26W
Chaseburg	21
Chaska	24W
Chelsea	3
Chetek	8
Chilgren	24W
Clarion	15
Clontarf	6
Cloquet	8
Clyde	24W
Collinwood	25
Colo	24W
Colvin	24W
Comfrey	24W
Conic	2*(h)

Copaston	14
Cordova	24W
Cormant	3W
Crippin	15W
Cromwell	5
Cushing	16
Cutfoot	1
Cylinder	12
Dakota	13
Dalbo	25
Darfur	12
Darnen	15
Dassel	3W*(t)
Dawson	26W
Deerwood	4W
Derinda	24
Dickinson	6
Dickman	5
Dodgeville	23
Doland	22
Donaldson	17
Donnan	17
Dorchester	20
Dorset	8
Dovray	25W
Downs	20
Dubuque	23
Duelm	3W
Duluth	16
Dundas	15W
Dunnville	13
Dusler	15W
Egeland	9
Elderon	8
Eleva	7*(h)
Emmert	1
Enstrom	4
Erin	24*(t)
Estelline	19
Estherville	8
Etter	7
Everly	24
Fairhaven	19
Fargo sicl	25W
Fargo sic	25W
Fargo-Ryan complex	25W
Farrar	9
Fayette	21
Fedji	4
Fieldon	12W
Flak	18
Flaming	3
Flandreau	13
Flom	24W
Foldahl	4
Forada	12W
Fordville	12
Forman	24
Formdale	24
Fossum	3W
Foxhome	9
Fram	15W
Freeon	21
Freer	18W
Frontenac	20
Fulda	25W
Gale	23
Galva	24
Garnes	16
Garwin	24W
Glencoe	24W
Glyndon	15
Gonvick	24
Gotham	3
Granby	3W
Grays	20
Greenwood muck or mucky peat	26W
Grimstad fsl	9
Grogan	20
Growton	9
Grygla	4W
Guckeen	25
Halder	12W
Hamar	3W
Hamel	15W
Hamerly	16
Hangaard	12W
Hanska	12W
Hantho	20
Harps	24W
Harpster	24W
Hattie	25
Haug	15W
Havana	24W
Hayden fsl or sl	16
Hayden l or sil	16
Hayfield	13
Hecla	3
Hegne-Fargo complex	25W
Hesch	7
Heyder	9
Hibbing	25
Hidewood	24W
Hillet	12W
Histosols, flooded	26W
Histosols, undifferentiated	26W

Hiwood	3
Hixton	14*(s)
Holdingford	18
Houghton	26W
Hubbard	2
Huntsville	20
Ihlen	23*(h)
Indus	25W
Isan	3W
Isanti	3W
Jackson	19
Joliet	23W
Joy	24
Judson	24
Kamrar	24
Kanaranzi	11
Karlstad	1
Kasota	24*(u)
Kasson	24
Kato	24W*(u)
Kegonsa	24*(u)
Kennebec	20
Kenyon	15
Kilkenny	24
Kingsley	9
Kingston	24
Kittson	15
Klinger	24W
Kranzburg	24
Kratka	4
Lamont	6
Lamoure	24W
Langhei	16
Langola	4
LaPrairie	20
Lasa	3
Lawson	20
Lemond	12W
Leota	24W
Lerdal	24
Lester l or sil	15
LeSueur	15
Letri	24W
Lilah	8
Linder	12W
Lindstrom	20
Lino	3
Lismore	24
Litchfield	3
Lobo	26W
Lohnes	2
Lomax	13
Loxley	26W
Lupton	26W
Lura	25W
Lyra	24W
Maddock	3
Madelia	24W
Malachy	6
Marcus	24W
Markey	26W
Marna	24W
Marquette	1
Marshan	12W
Marysland	12W
Mavie	15W
Maxcreek	24W
Maxcreek, swales	24W
Maxfield	24W
Mayer	12W
Mazaska	24W
McDonaldsville	25W*(u)
McIntosh	22
McPaul	20
Medary	24
Meehan	3
Menahga	2
Meridian	13
Merton	22
Merwin	26W
Metogga	26W
Milaca	18
Millerville	26W
Millington	24W
Minneopa	5
Minnetonka	25W
Minnielska	19
Moland	22
Moody	24
Mooselake	26W
Mora	18
Mosomo	3
Mt. Carroll	21
Muscatine	24
Muskego	26W
Nebish sl or fsl	16
Nemadji	3W
Nereson	15
Nessel sl or fsl	16
Newfound	18
Newry	21
Newson	3W
Nicollet	15
Nokasippi	4W
Nokay	18
Northcote	25W

Nowen	9W
Noyes	25W
Nutley	25
Nymore	2
Ocheyedan	15
Ogilvie	12W
Oldham	24W
Omega	2
Onamia	8
Ontonagon	25
Opole	18
Orion	21
Osakis	8
Oshawa	24W
Ostrander	15
Otterholt	22
Paget	18
Palms	26W
Parent	18W
Parnell	24W
Pelan	9W
Percy, calcareous surface	15W
Perella	24W
Plainfield	2
Poinsett	20
Pomroy	4
Poppleton	3
Port Byron	20
Prebish	18W
Primghar	24W
Quam	24W
Racine	20
Radford	24W
Ransom	24
Rasset	8
Rauville	24W
Readlyn	15W
Redby	3
Renova	21
Renshaw	11
Rib	19
Richwood	21
Rifle	26W
Rockton	14
Rockwell fsl	15W
Rockwood	18
Rolfe	25W
Roliss	15W
Rondeau	26W
Ronneby	18W
Rosholt	8
Rothsay	20
Rushmore	24W
Sac	24
Salida	1
Santiago	21*(u)
Sargeant	24W
Sartell	3
Sattre	13
Schapville	24
Seaton	21
Seelyeville	26W
Shawano	3
Shible	6
Shields	24W
Shooker	15W
Shorewood sicl	25
Shullsburg	25W
Sigsbee	25W
Sinai	25
Sioux	1
Skyberg	21
Soderville	3
Sparta	3
Spencer	22
Spicer	24W
Spillville	15
Spooner	15W
Spottswood	12
Storden	16
Strandquist	9W
Stronghurst	24W
Stuntz	15W
Suamico	26W
Svea	15
Sverdrup	5
Swenoda	9
Syrene	12W
Talcot	12W
Tallula	20
Tama	24
Tara	22
Taylor	25
Terril	15
Tilfer	23
Timula	21
Toivola	1
Tonka	24W
Torning	10
Towner	9
Trent	24
Tripoli	24W
Trosky	24W
Truman	21
Twig and Parent soils	24W
Udolpho	24W*(u)

Ulen	3
Upsala	18W
Urness	24W
Vallers	24W
Vasa	21
Venlo	3W
Vienna	24
Viking	25W
Vlasaty	21
Volin	20
Wadena	12
Wahpeton	25
Waldorf	24W
Warba	24
Warman	12W
Waskish	26W
Watab	4W
Waubay	24
Waukegan	19
Waukon	24
Webster	24W
Whalan	23
Wheatville	17
Whitewood	24W
Wilmington	24
Winger	24W
Zell-Rothsay complex	21
Zimmerman	3
Zumbro	2
Zwingle	25W

Soils differ slightly from group description.

h - hard rock
s - sandstone
t - surface texture
u - underlying texture

IRRIGATION GROUPS

Group 1 - Intake Family 3

Sand very shallow to sand and gravel, excessively drained.

Cutfoot	Karlstadt	Salida	Toivola
Emmert	Marquette	Sioux	

Representative Profile			A W C	
		Incremental	Incremental	Cumulative
Depth (In.)	Texture	Inches/Inch	Inches	Inches
0 - 12	Gravelly loamy sand	.06	.72	
12 - 24	Sand & gravel	.03	.36	1.08
24 - 36	Sand & gravel	.03	.36	1.44
36 - 60	Sand & gravel	.03	.72	2.16

Group 2 - Intake Family 3

Deep, sand, excessively drained.

Bellechester	Lohnes	Nymore	Plainfield
Conic	Menahga	Omega	Zumbro
Hubbard			

Representative Profile			A W C	
		Incremental	Incremental	Cumulative
Depth (In.)	Texture	Inches/Inch	Inches	Inches
0 - 12	Sand	.09	1.08	
12 - 24	Sand	.06	.72	1.80
24 - 36	Sand	.06	.72	2.52
36 - 60	Sand	.06	1.44	3.96

Group 3 - Intake Family 2

Loamy coarse sand, loamy sand, fine sand or loamy fine sand underlain by fine sand, excessively to somewhat poorly drained.

Bena	Hiwood	Redby	Soderville
Boone	Lasa	Sartell	Sparta
Chelsea	Litchfield	Shawano	Ulen
Flaming	Maddock	Soderville	Zimmerman
Gotham	Meehan		
Hecla	Poppleton		

Representative Profile			A W C	
		Incremental	Incremental	Cumulative
Depth (In.)	Texture	Inches/Inch	Inches	Inches
0 - 12	Loamy fine sand	.12	1.44	
12 - 24	Fine sand	.09	1.08	2.52
24 - 36	Fine sand	.08	.96	3.48
36 - 60	Fine sand	.08	1.92	5.40

Group 3W - Intake Family 2

Loamy coarse sand, loamy sand, fine sand or loamy fine sand underlain by fine sand, poorly and very poorly drained. Drainage practices are necessary prior to installation of irrigation system. Drained soil characteristics similar to Group 3.

Arveson	Duelm	Hamar	Isan
AuGres	Fossum	Nemadji	Isanti
Cormant	Granby	Newson	Venlo
Dassel			

Basic Drainage Requirements:

1. Control water table with open ditches 3.0 to 4.0 feet deep. Supplement with shallow surface drains. See the Minnesota Drainage Guide.

2. Control wind erosion to prevent filling of ditches.

Group 4 - Intake Family 2

Loamy sand, fine sand, or loamy fine sand underlain by loamy material, well and excessively drained.

Braham	Fedji	Kratka	Pomroy
Enstrom	Foldahl	Langola	

Representative Profile			A W C	
		Incremental	Incremental	Cumulative
Depth (In.)	Texture	Inches/Inch	Inches	Inches
0 - 12	Fine sand	.12	1.36	
12 - 24	Fine sand	.10	1.20	2.56
24 - 36	Fine sand	.10	1.20	3.76
36 - 60	Loam	.19	4.56	8.32

Group 4W - Intake Family 2

Loamy sand, fine sand, or loamy fine sand underlain by loamy material, poorly and very poorly drained. Drainage practices needed prior to installation of irrigation system. Drained soil characteristics similar to Group 4.

Aitken	Blomford	Grygla	Watab
Allendale	Deerwood	Nokasippi	

Basic Drainage Requirements:

1. Dispose of surface water with shallow surface drains. Refer to the Minnesota Drainage Guide for detailed recommendations.

2. Divert surface runoff from higher ground.

3. If tile are used, spacing will vary according to depth to fine material. Care is required in blinding the tile.

4. Prevent wind erosion from filling ditches.

Group 5 - Intake Family 1.5

Sandy loam or coarse sandy loam 12-20 inches thick over sand, excessively to moderately well drained.

Binford
Cromwell
Dickman
Minneopa
Sverdrup

Representative Profile			A W C	
		Incremental	Incremental	Cumulative
Depth (In.)	Texture	Inches/Inch	Inches	Inches
0 - 12	Sandy loam	.15	1.80	
12 - 18	Sandy loam	.12	.72	2.52
18 - 24	Sand	.06	.36	2.88
24 - 36	Sand	.06	.72	3.60
36 - 60	Sand	.06	1.44	5.04

Group 6 - Intake Family 1.5

Fine sandy loam 20-40 inches over sand, moderately well to excessively drained.

Amery
Ankeny
Alvin
Becker
Billet
Clontarf
Dickinson
Lamont
Malachy
Shible

Representative Profile			A W C	
		Incremental	Incremental	Cumulative
Depth (In.)	Texture	Inches/Inch	Inches	Inches
0 - 12	Fine sandy loam	.18	2.16	
12 - 24	Fine sandy loam	.15	1.80	3.96
24 - 36	Fine sandy loam	.15	1.44	5.40
36 - 60	Loamy sand	.09	2.16	7.56

Group 7 - Intake Family 1.5

Fine sandy loam, 20-40 inches over sandstone excessively drained. Limit irrigation to above the sandstone.

Arloud Eleva Etter Hesch

Representative Profile		Incremental	A W C Incremental	Cumulative
Depth (In.)	Texture	Inches/Inch	Inches	Inches
0 - 12	Fine sandy loam	.17	2.04	
12 - 24	Loam	.18	2.16	4.20
24 - 30	Loam	.18	1.08	5.28
30+ Sandstone				

Group 8 - Intake Family 1.5

Sandy loam 12-20 inches over sand and gravel, excessively drained. Limit irrigation to above the sand and gravel layer.

Arvilla	Burkhardt	Estherville	Osakis
Chetek	Burnsville	Lilah	Rassett
Cloquet	Dorset	Onamid	Rosholt

Representative Profile		Incremental	A W C Incremental	Cumulative
Depth (In.)	Texture	Inches/Inch	Inches	Inches
0 - 12	Sandy loam	.15	1.80	
12 - 18	Sandy loam	.12	.72	2.52
18 - 24	Sand & gravel	.04	.24	2.76
24 - 60	Sand & gravel	.03	1.08	3.84

Group 9 - Intake Family 1.5

Sandy loam, well and moderately well drained.

Blowers	Foxhome	Heyder	Swenoda
Egeland	Grimstad	Kingsley	Towner
Farrar	Growton		

Representative Profile			A W C	
Depth (In.)	Texture	Incremental Inches/Inch	Incremental Inches	Cumulative Inches
0 - 12	Sandy loam	.14	1.60	
12 - 24	Loamy fine sand	.09	1.08	2.68
24 - 36	Loamy fine sand	.09	1.08	3.76
36 - 60	Sandy loam	.12	2.88	6.64

Group 9W - Intake Family 1.5

Sandy loam, somewhat poor and poorly drained. Drainage practices needed prior to installation of irrigation system. Drained soil characteristics similar to Group 9.

Nokay	Nowen	Pelen	Strandquist

Basic Drainage Requirements:

1. Surface drainage is needed to remove runoff and is most effective with land smoothing.

2. Internal drainage with tile is effective. However, stoniness may make installation of tile difficult and expensive. Refer to the Minnesota Drainage Guide for spacing and depth.

Group 10 - Intake Family 1.5

Very fine sand, loamy very fine sand or very fine sandy loam, well drained.

Anoka Edison Torning

Representative Profile			A W C	
		Incremental	Incremental	Cumulative
Depth (In.)	Texture	Inches/Inch	Inches	Inches
0 - 12	Very fine sand	.22	2.64	
12 - 24	Loamy very fine sand	.18	2.16	4.80
24 - 60	Very fine sand	.18	6.48	11.28

Group 11 - Intake Family 1.0

Loam or sandy clay loam, 12-20 inches over sand and gravel excessively drained. Limit irrigation to above the sand and gravel layer.

Kanaranzi Renshaw

Representative Profile			A W C	
		Incremental	Incremental	Cumulative
Depth (In.)	Texture	Inches/Inch	Inches	Inches
0 - 12	Loam	.22	2.64	
12 - 18	Loam	.18	1.08	3.72
18 - 24	Sand and gravel	.04	.24	3.96
24 - 60	Sand and gravel	.03	.72	4.68

Group 12 - Intake Family 1.0

Loam or sandy clay loam, 20-40 inches over sand and gravel moderately well drained. Limit irrigation to above the sand and gravel layer.

Cylinder Darfur Fordville Spottswood Wadena

Representative Profile			A W C	
		Incremental	Incremental	Cumulative
Depth (In.)	Texture	Inches/Inch	Inches	Inches
0 - 12	Loam	.22	2.64	
12 - 24	Loam	.18	2.16	4.80
24 - 30	Loam	.18	1.08	5.88
30 - 60	Sand and gravel	.03	.90	6.78

Group 12W - Intake Family 1.0

Loam, very fine sandy loam, loamy very fine or sandy clay loam, 20 to 40 inches over sand and gravel, poor and very poorly drained. Drainage practices needed prior to installation of irrigation system. Drained soil characteristics similar to Group 12.

Benoit	Halder	Linder	Ogilvie
Biscay	Hanska	Marshan	Syrene
Darfur	Hangaard	Marysland	Talcot
Fieldon	Hillet	Mayer	Warman
Forada	Lemond		

Basic Drainage Requirements:

1. Install surface water removal system.

2. Control water table with ditches about 4' deep, space 200 to 400 feet apart. Refer to the Minnesota Drainage Guide.

3. Tile drainage is effective in lieu of ditches but precautions are necessary in blinding tile and other construction phases.

Group 13 - Intake Family 1.0

Loam, very fine sandy loam, loamy very fine sand or sandy clay loam 20-40 inches over sand, well and excessively drained.

Bixby	Dunnville	Hayfield	Meridian
Dakota	Flandreau	Lomax	Sattre

Representative Profile			A W C	
		Incremental	Incremental	Cumulative
Depth (In.)	Texture	Inches/Inch	Inches	Inches
0 - 12	Loam	.21	2.52	
12 - 24	Loam	.18	2.16	4.68
24 - 30	Loam	.18	1.08	5.76
30 - 60	Sand	.06	1.80	7.56

Group 14 - Intake Family 1.0

Loam or sandy clay loam, 20-40 inches over bedrock. Limit irrigation to above bedrock.

Hixton Rockton

Representative Profile			A W C	
Depth (In.)	Texture	Incremental Inches/Inch	Incremental Inches	Cumulative Inches
0 - 12	Loam	.20	2.40	
12 - 24	Loam	.18	2.16	4.56
24 - 36	Sand	.06	.72	5.28
36 - +	Bedrock			

Group 15 - Intake Family 1.0

Dark colored, loam or sandy clay loam, well and moderately well drained.

Barnes	Heimdal	Lesuer	Ostrander
Clarion	Kenyon	Nereson	Spillville
Cresco	Kittson	Nicollet	Svea
Darnen	Lester	Ocheyedan	Terril
Glyndon			

Representative Profile			A W C	
Depth (In.)	Texture	Incremental Inches/Inch	Incremental Inches	Cumulative Inches
0 - 12	Loam	.22	2.64	
12 - 24	Loam	.19	2.28	4.92
24 - 36	Loam	.18	2.16	7.08
36 - 60	Loam	.18	4.32	11.40

Group 15W - Intake Family 1.0

Loam, very fine sandy loam, loamy very fine sand or sandy clay loam, poor and very poorly drained. Drainage practices needed prior to installation of irrigation system. Drained soil characteristics similar to Group 15.

Ames	Dundas	Haug	Roliss
Augsburg	Dusler	Mavie	Shooker
Barrows	Floyd	Percy	Spooner
Borup	Fram	Readlyn	Stuntz
Crippin	Hamel	Rockwell	

Basic Drainage Requirements:

1. Install surface drains.

2. Tile spacing varies widely in this group. Consult SCS Drainage Guide for specific depth and spacing.

Group 16 - Intake Family 1.

Light colored, loam or sandy clay loam, well and moderately well drained.

Beltrami	Duluth	Hayden	Nessel
Buse	Garness	Langhei	Storden
Cushing	Hamerly	Nebish	

			A W C	
Representative Profile		Incremental	Incremental	Cumulative
Depth (In.)	Texture	Inches/Inch	Inches	Inches
0 - 12	Loam	.20	2.40	
12 - 24	Clay loam	.19	2.28	4.68
24 - 36	Clay loam	.19	2.28	6.96
36 - 60	Loam	.19	4.56	11.52

Group 17 - Intake Family 1.0

Loam or sandy clay loam 24-40 inches over clay, moderately well to somewhat poorly drained, moderately slow to slow permeability.

Donaldson Donnan Wheatville

Representative Profile		Incremental	A W C Incremental	Cumulative
Depth (In.)	Texture	Inches/In.	Inches	Inches
0 - 12	Sandy clay loam	.21	2.52	
12 - 24	Sandy clay loam	.18	2.16	4.68
24 - 30	Very fine sandy loam	.18	1.08	5.76
30 - 60	Clay	.15	4.50	10.26

Group 18 - Intake Family 1.0

Sandy loam, loam or sandy clay loams with fragipan layers below 24 inches, well drained and moderately well drained.

Ahmeeki	Flak	Mora	Opole
Bock	Holdingford	Nokay	Paget
Brainerd	Milaca	Newfound	Rockwood

Representative Profile		Incremental	A W C Incremental	Cumulative
Depth (In.)	Texture	Inches/Inch	Inches	Inches
0 - 12	Loam/sandy loam	.16	1.92	
12 - 24	Sandy loam	.12	1.44	3.36
24 - 36	Sandy loam	.11	1.32	4.68
36 - 60	Sandy loam	.11	2.64	7.32

Group 18 W - Intake Family 1.0

Sandy loam, loam or sandy clay loam with fragipan layers, somewhat poor, poor or very poorly drained. Drainage practices needed prior to installation of irrigation system. Drained soil characteristics similar to Group 18.

Freer	Prebish	Ronneby	Upsala
Parent			

Basic Drainage Requirements:

1. Provide surface drains and land smoothing.

2. Tile drainage is effective but stoniness may make installation difficult and costly.

3. Refer to the Minnesota Drainage Guide for specific recommendations.

Group 19 - Intake Family .5

Silt loam 20-40 inches thick over sand and gravel, moderately well to well drained. Limit irrigation to above sand and gravel.

Almena	Brill	Jackson	Rib
Antigo	Estelline	Minneiska	Waukegan
Athelwold	Fairhaven		

Representative Profile			A W C	
		Incremental	Incremental	Cumulative
Depth (In.)	Texture	Inches/Inch	Inches	Inches
0 - 12	Silt loam	.24	2.88	
12 - 24	Silt loam	.20	2.40	5.28
24 - 36	Silty clay loam	.20	2.40	7.68
36 - 60	Sand and gravel	.03	.72	8.40

Group 20 - Intake Family .5

Dark colored silt loam moderately well and well drained.

Alcester	Grays	Laprairie	Racine
Barrington	Grogan	Lawson	Rothsay
Bearden sil	Hantho	Lindstrom	Tallula
Beotia	Huntsville	McPaul	Volin
Dorchester	Joy	Poinsette	
Downs	Kennebec	Port Byron	
Frontenac			

Representative Profile			A W C	
Depth (In.)	Texture	Incremental Inches/Inch	Incremental Inches	Cumulative Inches
0 - 12	Silt loam	.28	3.36	
12 - 24	Silt loam	.20	2.40	5.76
24 - 36	Silt loam	.20	2.40	8.16
36 - 60	Silt loam	.20	4.80	12.96

Group 21 - Intake Family .5

Light colored silt loam, moderately well and well drained.

Alstad	Chasburg	Orion	Timula
Arenzville	Crofton	Renova	Truman
Baudette	Fayette	Richwood	Vasa
Bertrand	Freeon	Santiago	Vlasaty
Bold	Mt. Carroll	Seaton	Zell
Campia	Newry	Skyberg	

Representative Profile			A W C	
Depth (In.)	Texture	Incremental Inches/Inch	Incremental Inches	Cumulative Inches
0 - 12	Silt loam	.22	2.64	
12 - 24	Silt loam	.20	2.40	5.04
24 - 60	Silt loam	.20	7.20	12.24

Group 22 - Intake Family .5

Silt loam 12-20 inches over loam or light clay loam, moderately well and well drained.

Blooming	McIntosh	Moland	Spencer
Doland	Morton	Otterholt	Tara

Representative Profile			A W C	
Depth (In.)	Texture	Incremental Inches/Inch	Incremental Inches	Cumulative Inches
0 - 12	Silt loam	.26	3.12	
12 - 24	Silt loam	.20	2.40	5.52
24 - 60	Loam	.18	6.48	12.00

Group 23 - Intake Family 0.5

Silt loam 20-40 inches over bedrock, well drained. Limit irrigation to above bedrock.

Dodgeville	Dubuque	Gale	Whalan

Representative Profile			A W C	
Depth (In.)	Texture	Incremental Inches/Inch	Incremental Inches	Cumulative Inches
0 - 12	Silt loam	.27	3.12	
12 - 18	Silt loam	.20	1.20	4.32
18 - 24	Silty clay loam	.20	1.20	5.52
24 - 36	Clay	.14	1.68	7.20
36 - 60	Bedrock			

Group 23 W - Intake Family 0.5

Silt loam 20 to 40 inches over bedrock, poorly and very poorly drained. Drainage practices needed prior to installation of irrigation system. Drained soil characteristics similar to Group 23.

Faxon	Joliet	Tilfer

Basic Drainage Requirements:

1. Control water table with intercepter drains or deep ditches.
2. Minimum depth for tile may not be attainable.
3. Refer to the Minnesota Drainage Guide for specific information.

Group 24 - Intake Family 0.3

Clay loam or silty clay loam moderately well and well drained, moderately slow permeability, high AWC.

Aastad	Galva	Kilkenny	Sac
Aazdahl	Gonvick	Kingston	Schapville
Bearden	Ihlen	Kranzburg	Tama
Brookings	Joy	Lerdal	Trent
Derinda	Judson	Lismore	Trosky
Erin	Kamrar	Medary	Vienna
Everly	Kasota	Moody	Waubay
Forman	Kasson	Muscatine	Waukon
Formdale	Kegonsa	Ransom	Wilmonton

Representative Profile			A W C	
		Incremental	Incremental	Cumulative
Depth (In.)	Texture	Inches/Inch	Inches	Inches
0 - 12	Clay loam	.23	2.76	
12 - 24	Clay loam	.20	2.40	5.16
24 - 60	Clay loam	.20	7.20	12.36

Group 24 W - Intake Family 0.3

Clay loam or silty clay loam, well, somewhat poorly, poorly and very poorly drained. Drainage practices needed prior to installation of irrigation system. Drained soil characteristics similar to Group 24.

Aberdeen	Comfrey	Marcus	Sargeant
Adolph	Cordova	Marna	Shields
Antler	Flom	Maxcreek	Spicer
Auburndale	Garwin	Maxfield	Stronghurst
Blackhoof	Glencoe	Mazaska	Tonka
Blue Earth	Harps	Millington	Tripoli
Bluffton	Harpster	Oldham	Trosky
Bremer	Havana	Oshawa	Twig
Brownton	Hidewood	Parnell	Udolpho
Calamine	Kato	Perella	Urness
Calco	Klinger	Primgar	Vallers
Canisteo	Lamoure	Quam	Waldorf
Chaska	Leota	Radford	Webster
Chilgren	Letri	Rauville	Whitewood
Clyde	Lyra	Rushmore	Winger
Colo	Madelia		
Colvin			

Basic Drainage Requirements:

1. Install surface drains and divert runoff from higher ground.

2. Tile spacing varies widely in this group. Consult SCS drainage guides for specific depth and spacing.

Group 25 - Intake Family 0.1

Clay, moderately well and well drained.

Arcola	Guckeen	Nutley	Sinai
Beauford	Hattie	Ontonagon	Taylor
Collinwood	Hibbing	Shorewood	Wahpeton
Dalbo			

Representative Profile			A W C	
Depth (In.)	Texture	Incremental Inches/Inch	Incremental Inches	Cumulative Inches
0 - 12	Clay	.19	2.28	
12 - 24	Clay	.15	1.80	4.08
24 - 60	Clay	.15	5.40	9.48

Group 25 W - Intake Family 0.1

Clay, poor and very poorly drained. Drainage needed prior to installation of irrigation system. Drained soil characteristics similar to Group 25.

Afton	Cashel	Indus	Rolfe
Barbert	Dovray	Lura	Shakopee
Baroda	Fargo	McDonaldsville	Shullsburg
Bergland	Fulda	Minnetonka	Sigsbee
Brickton	Hegne	Northcote	Viking
		Noyes	Zwingle

Basic Drainage Requirements:

1. Install surface drainage system.

2. Divert runoff from higher ground.

3. Tile spacing ranges from 50 to 100 feet. Refer to the Minnesota Drainage Guide.

Group 26 W - Organic Soils

Very poorly drained organic soils. Drainage is needed prior to installation of irrigation system.

Adrian	Dawson	Markey	Palms
Beseman	Greenwood	Merwin	Rifle
Boots	Houghton	Metogga	Rondeau
Brophy	Lobo	Millerville	Seelyeville
Carlos	Loxley	Moose Lake	Suamico
Caron	Lupton	Muskego	Waskish
Cathro			

Basic Drainage Requirements:

1. Open ditch water table control. Water control structures may be necessary to control water table.

2. Tile drains may supplement open ditches especially if under ain by mineral soil at shallow depths.

3. Refer to the Minnesota Drainage Guide.

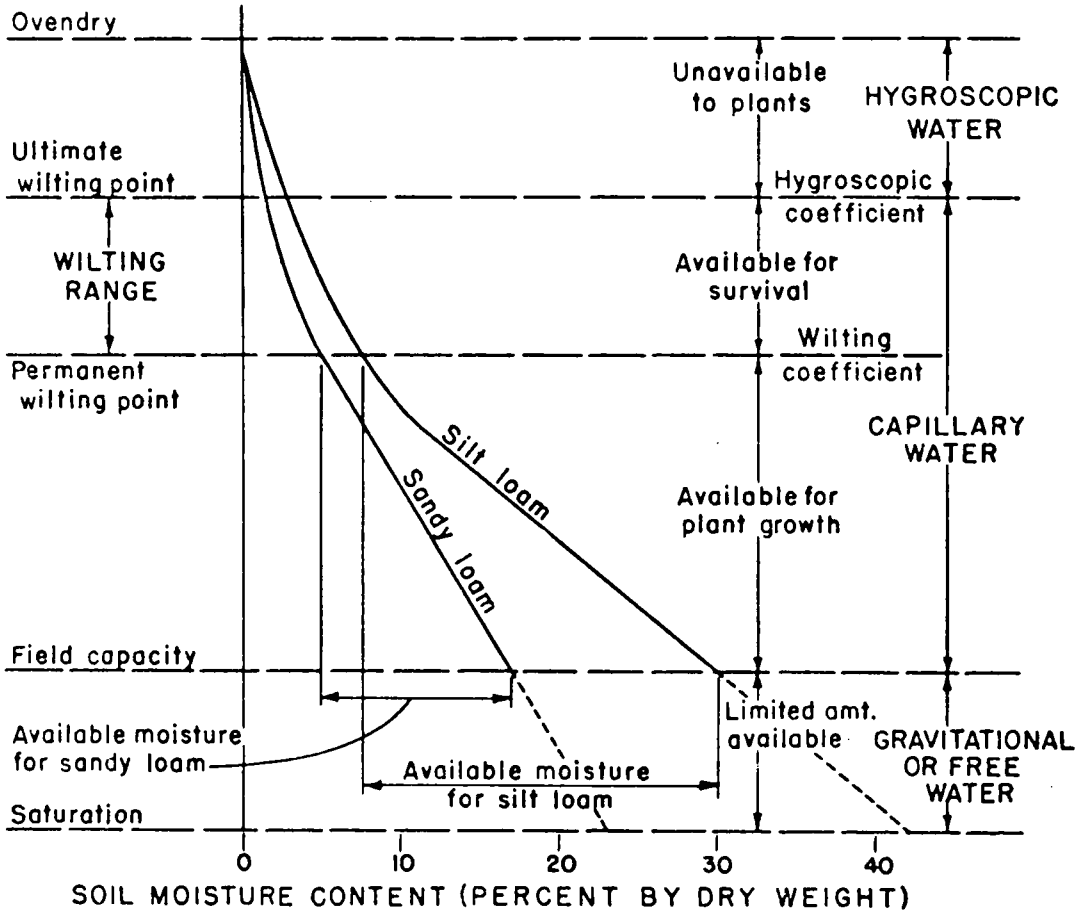

Figure 3-1.--Kinds of water in the soil and difference in available-moisture content between a sandy loam and a silt loam. The silt loam contains more than twice as much readily available water.

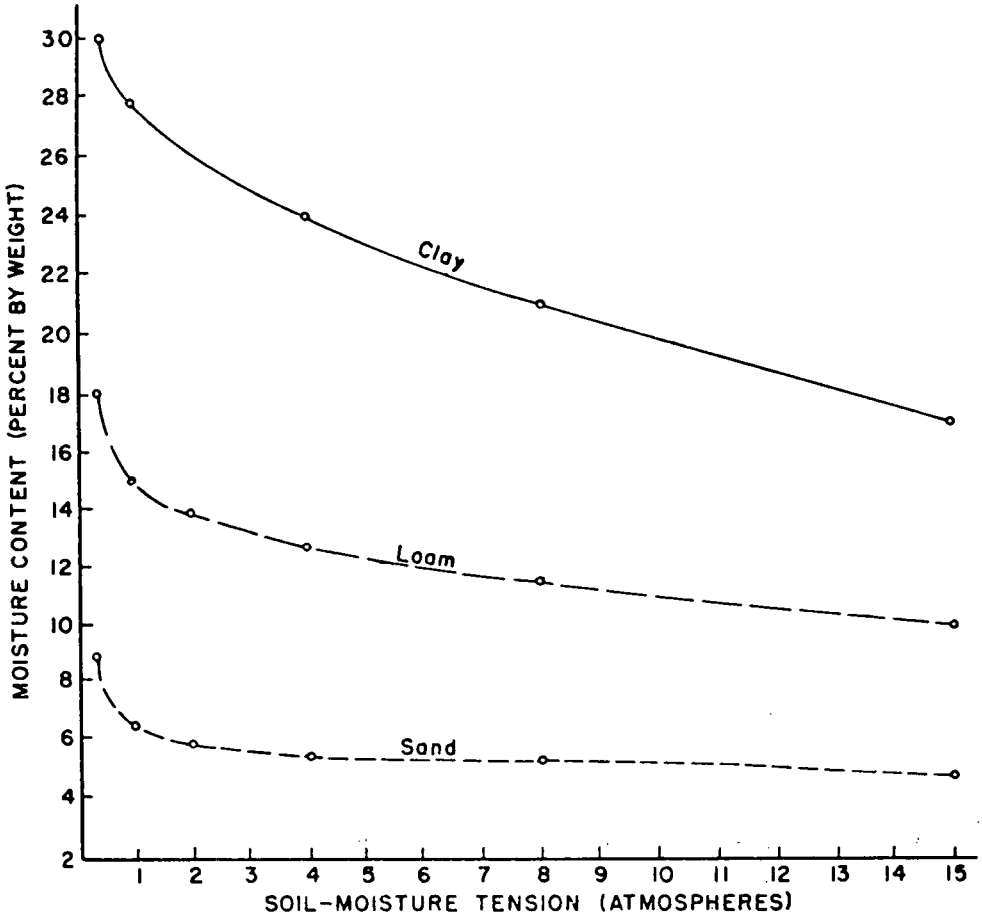

Figure 3-2.--Moisture-characteristic curves. (From Thorne, M.D., and Raney, W. A. Soil Moisture Evaluation. U.S. Dept. Agr. ARS 41-6. 14 pp., illus. 1956.)

Drainage

Good drainage, both surface and internal, is essential to realize the anticipated benefits from irrigation. If the land is not naturally well drained, artificial drainage must be established before or at the same time the irrigation system is installed. A working knowledge of drainage is necessary to plan a satisfactory irrigation system. A basic fundamental of drainage is that only the gravitational, or free water, is removed from the soil. The moisture and air relationship conducive to plant growth is attained only when the free water is allowed to drain. Figures 3-1 and 3-2 illustrate this concept.

In humid areas, subsurface drainage is highly important if the soils are permeable enough for subsurface drains to be effective in lowering the water table to the depth required for good growing conditions. Surface drainage is always needed to remove excess runoff. Wet soils that delay planting in the spring, impede crop growth, and delay harvesting cannot be irrigated successfully. Water lost through deep percolation increases the amount of ground water in a soil and may cause the water table to rise to a level at which crops are damaged. Subsurface drains are then necessary. Specific drainage recommendations for a particular soil are found in the Minnesota Drainage Guide. This guide is available at Soil Conservation Service Field Offices.

Seepage from irrigation ditches can damage land and waste water. If site conditions require conveying water across gravelly, sandy, or other excessively permeable areas, the irrigation system design must provide for pipelines, flumes, or lined ditches as needed to prevent loss of water by seepage into the soil. Proper seepage control reduces the need for drainage.

Erosion Control

Erosion, by either irrigation water or rain, can be a hazard to the operation and maintenance of an irrigation system. Furthermore, high yields of irrigated crops cannot be maintained on eroding land. Irrigation should not be planned for land subject to erosion until erosion control measures have been established or are provided for in the irrigation system. Erosion control practices and the irrigation system need to be fitted together for ease of operation and uniform distribution of water. Some soils are more susceptible to erosion than others. The erodibility of the soils to be irrigated needs to be considered and the factors that cause erosion evaluated and allowed for in planning the irrigation system.

Water erosion may be caused by the irrigation stream, runoff from adjacent areas, or water that falls directly on the irrigated area, either as rainfall or from sprinklers. Provision must be made for conveying and distributing irrigation water without causing erosion. The rate to which water is applied must be controlled so that it does not cause erosion. Some movement of soil particles always occurs when water flows over loose, bare soil.

If sprinklers are to be used, the design rate of application must not cause runoff that adds to the erosion hazard. This is particularly true in humid areas where a heavy rainstorm immediately after an irrigation may cause excessive runoff. Size of the drops from the sprinklers also is important. Large drops dislodge particles of soil that can easily be carried away by runoff water. On bare field, new seedings, and row crops; rain or sprinkler irrigation may compact and seal the soil surface. This reduces water absorption and increases the erosion hazard. A crop cover or mulch dissipates the energy of falling water, and there is little or no surface sealing or erosion. In areas where the rate of precipitation is likely to exceed a soil's intake rate, runoff and erosion may be a problem. This problem usually can be handled by installing conservation practices such as minimum tillage, contour farming, or cross slope farming. If runoff from adjacent areas is likely to cause erosion or flooding, plans must be made for either the diversion or controlled conveyance of the runoff water. The universal soil loss equation will be used to determine the soil loss potential in planning treatment needed to control erosion.

Wind erosion may remove surface soil or deposit soil material on other areas. Soil blowing can usually be controlled by crop residue management, cover cropping, wind strips, tillage, or shelter belts. Some crops have very low tolerance to soil blowing. Planned protection will be based on the wind erosion equation. But these measures may lead to soil accumulation if adjacent areas are not similarly protected. Therefore, the planner must not only determine the probability of wind erosion on the area to be irrigated, but also consider conditions on adjacent areas before selecting an irrigation method. Conservation practices planned must be compatible with the irrigation system. Since canals, ditches, and other open structures may be rapidly filled by windborne materials, consider using closed conduits where this hazard exists.

In irrigation systems where earth embankments, such as dams, canal banks, and border ridges or levees are a part of the system, these may be damaged by wave action if long open reaches are parallel to the prevailing wind direction. This hazard can be overcome by locating these structures so as to reduce the fetch or by using riprap and other protective measures such as false berms or baffles.

Consideration must be given to potential erosion hazards when planning for irrigation. Refer to Chapter 4, Step 12, of the example problem on Center Pivot System Design - Adequate water supply for a typical analysis of water and wind erosion hazard.

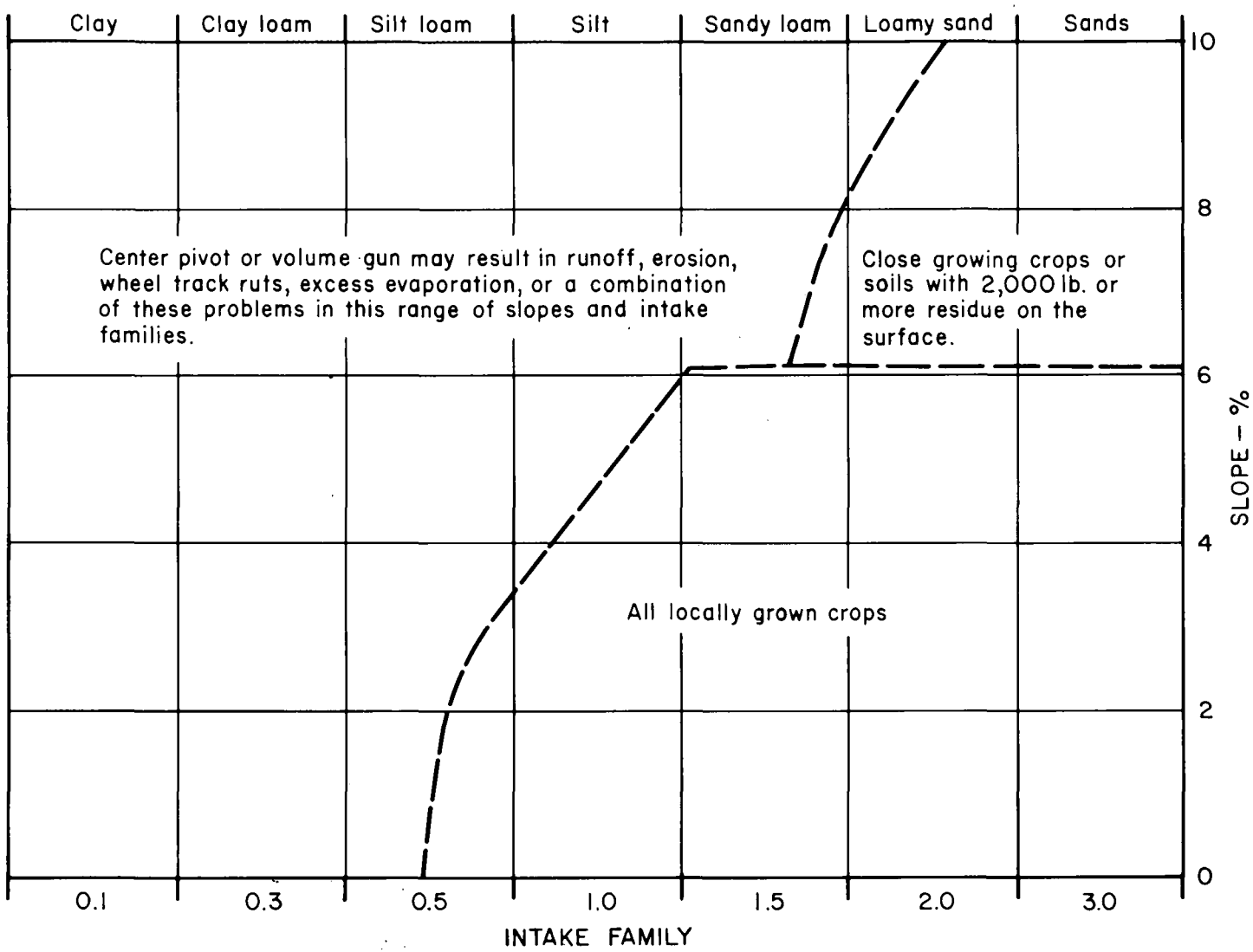

Figure 3-3 Guide for Use of Irrigation Systems With High Application Rates

CHAPTER 4 - SPRINKLER SYSTEM PLANNING AND DESIGN

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TYPES OF SPRINKLER IRRIGATION

The following discussion is aimed at giving guidelines for the selection of the type of equipment best suited and design requirements that the selected equipment should meet.

In sprinkler irrigation, the water is sprayed into the air and allowed to fall on the land surface in a uniform pattern at a rate approximately equal to or less than the intake rate of the soil. This method of water application is similar to rainfall.

If the system is properly designed and operated, efficiencies of 65% to 75% can be obtained. Sprinkler losses are due to evaporation losses in the air by the sprinkler spray, evaporation from the soil surface or moisture intercepted on the leaves during irrigation, and non-uniform distribution due to the sprinkler pattern. Winds distorts the pattern and frequently this results in non-uniform application.

Intake rates under sprinkler irrigation do not conform to those for flood or furrow irrigation. Table 3-4 has been prepared as a guide for maximum application rate and a sprinkler system that will apply water at a rate equal to or less than shown in the table will be satisfactory to use in applying irrigation water.

Types of Sprinklers (Nozzles)--Sprinklers spray the water onto the land through nozzles in the sprinkler heads. These are classified according to the pressure required for proper distribution of the water applied.

Low Pressure Sprinklers. They operate at 5 to 15 pounds per square inch with a wetted diameter of 20 to 50 feet and a recommended minimum application rate of 0.40-inch per hour. These sprinklers are adapted to small acreages and where gravity pressure can be utilized but confined to soils with intake rates exceeding 0.50-inch per hour.

Moderate Pressure Sprinklers. They are usually single nozzle sprinklers with an operating pressure of from 15 to 30 p.s.i., a wetted diameter coverage of 60 to 80 feet, and a minimum application rate of 0.20-inch per hour. Moderate pressure sprinklers are adapted primarily to under-tree sprinkling in orchards.

Intermediate Pressure Sprinklers. Either single or dual nozzle design with operating pressures of 30 to 60 p.s.i., and a wetted diameter coverage of 75 to 125 feet with a minimum application rate of 0.25 inch per hour. This type sprinkler is probably the most popular because it can be adapted to a wide variety of soils and crops.

High Pressure Sprinklers. They may be either single or dual nozzle design with operating pressures of 50 to 100 p.s.i., providing a wetted diameter coverage of 110 to 230 feet with a minimum application rate of 0.50-inch per hour. Sprinklers of this type are primarily adapted to truck crops, field crops and pastures, particularly on

finer textured soils. They provide fast coverage with limited equipment. However, excessive wind presents a problem.

Hydraulic or Giant Sprinklers. This type of sprinkler has one large nozzle with smaller supplemental nozzles to fill in pattern gaps and operate at pressures of 80 to 120 p.s.i. They cover a wetted diameter from 200 to 400 feet with a minimum application rate of 0.65-inch per hour. Adapted to irrigation of pastures, tall growing crops, and where rapid coverage is desired. They are limited to soils with high intake rates.

Under-Tree, Low Angle Sprinklers. This sprinkler is designed to keep stream projectories below fruit and foliage by lowering the nozzle angle. Operating pressure varies from 10 to 50 p.s.i., providing a wetted diameter of 40 to 90 feet, with a minimum application rate of 0.33-inch per hour. They are adapted to orchards where the irrigation spray will damage soft fruits, where wind will distort over-tree sprinklers, and where available pressure is low.

Perforated Pipe Sprinklers. Water is sprayed out of several holes in the upper part of the portable irrigation pipe lateral. Usually several rows of perforations are used so that the jets of water cover a rectangular strip 10 to 50 feet wide. They can be operated on pressures of 4 to 20 p.s.i. The recommended minimum application rate is 0.50-inch per hour. They are for low-growing crops on soils of relatively high intake rates, best adapted to small acreages of high value crops. Low operating pressure permits use of gravity or municipal supply.

Types of Systems: All irrigation systems use a series of one or more of the above types of nozzles to distribute the water. Water is conveyed to these nozzles through either stationary or movable pipelines and the operation of these pipelines determines the type of system employed.

Hand-Moved Systems: The lateral line pipe and sprinklers are set at one location and allowed to remain there until the desired irrigation is obtained. They are then moved by hand from this position to another and the operation repeated. This is therefore a set-type system. Quick-coupled aluminum pipe is the best for most portable laterals. This is generally the cheapest type of system. However, considerable labor is required for moving the pipe. Figure 4-1 shows the general layout and operation of typical set-type distribution systems, one of which is the hand-move. It also shows the water source in the center of the field, although it could be at another point with the mainline located through the center of the field.

When a lateral line reaches the end of the field, it is disassembled and either moved back to its original location or across the mainline to the original location of the other lateral. The lateral lines must be moved to the starting location so that the area which was sprinkled first will again be sprinkled first in the following cycle.

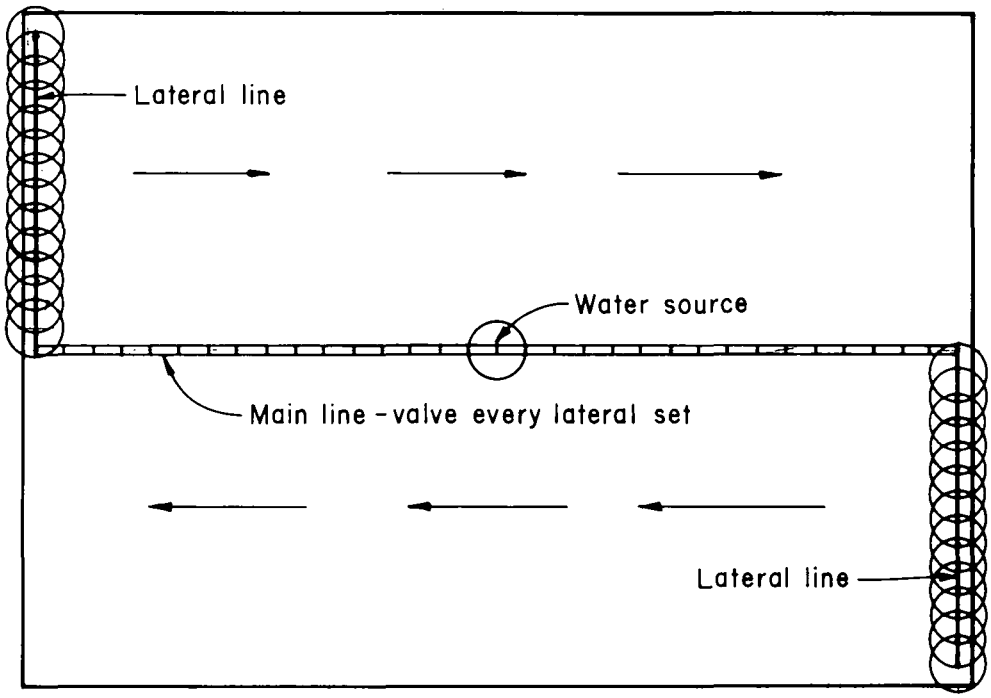


Figure 4-1. Set-type Irrigation System

Generally, to keep labor costs as low as practical, the design should be such that the required irrigation is applied in either a 7 or 11 hour time of set to allow either 3 or 2 sets per day with an hour allowed each setting for moving the pipe.

Advantages and Limitations: Can be used on irregularly shaped fields and rolling terrain; inconvenient for tall crops. Can use any nozzles from low to high pressure and can meet any intake requirement.

Side-Roll System: To decrease the amount and intensity of labor required, the lateral line is mounted on wheels. The pipe is the axle with the wheels usually spaced 30 feet apart and the sprinklers midway between. Wheels are available in different diameters with the largest wheels used for the maximum clearance.

The operation of the side-roll lateral is similar to the hand-move system. The lateral line is moved between sets by rolling the wheels. The distance between lateral sets depends on the size of the sprinklers. Usually this distance will be between 60 to 80 feet. The connection of the lateral to the mainline is usually made with a 10- to 15-foot section of flexible rubber hose.

When the side-roll system was first available, a large lever with a ratchet was used to move the system from one set to the next. Today most of the side-roll systems use air-cooled gasoline engines located near the center of the lateral line.

Because the pipe twists somewhat, it is necessary to provide for vertical alignment of the sprinkler. The self-aligning riser is a gooseneck device with a counter weight to keep the sprinkler vertical.

The side-roll system has been modified by some manufacturers by supporting the sprinkler lateral above the wheels on an "A" frame and using a drive shaft to move the system instead of using the pipe as an axle.

For a greater coverage width for a lateral set, side-roll systems have been developed which use trailing sprinkler lines each containing three or four sprinklers. These sprinklers, in addition to the sprinklers located on the main lateral, provide for set distances up to 300 feet. The field operation is the same as a hand-move or the conventional side-roll lateral system, except the coverage distance per set is considerably greater. The operation of this system is shown in figure 4-2.

When the lateral reaches the end of the field, it has to be moved back to the starting point or to an adjacent field and the trailing lines must be picked up and moved separately. Provision can be made to transport the trailing lines on the main lateral line. These systems often have a main lateral line supported on tower assemblies to provide clearance for tall crops.

Generally, design should be same as for hand-move systems.

Advantages and Limitations:

Requires rectangular fields, except when mounted on tower assemblies, these systems not adapted to tall crops. Can be used on any soil type suitable for sprinkler irrigation. Alignment may be difficult on undulating topography.

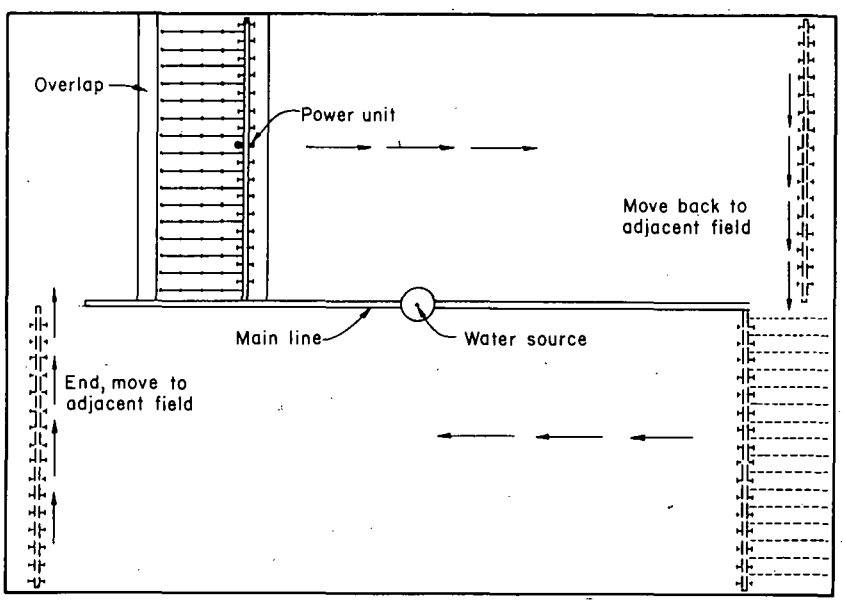


Figure 4-2. Operation of Trailing-line System

End-Tow Lateral

Another irrigation system using lateral sets is the end-tow or tractor-move system. The lateral line has couplers semipermanently fastened together. The lateral line may be mounted on skid pans or small wheels to be towed from one set to the next. The operation of a typical end-tow lateral line is shown in figure 4-3. The main line which supplies the water for the system is located in the center of the field. A turn strip 100 to 200 feet wide is provided so the lateral line can be turned as it is towed from one side of the field to the other. A typical system might have 60-foot sets so the lateral will need to be shifted 30 feet as it crosses the turn strip.

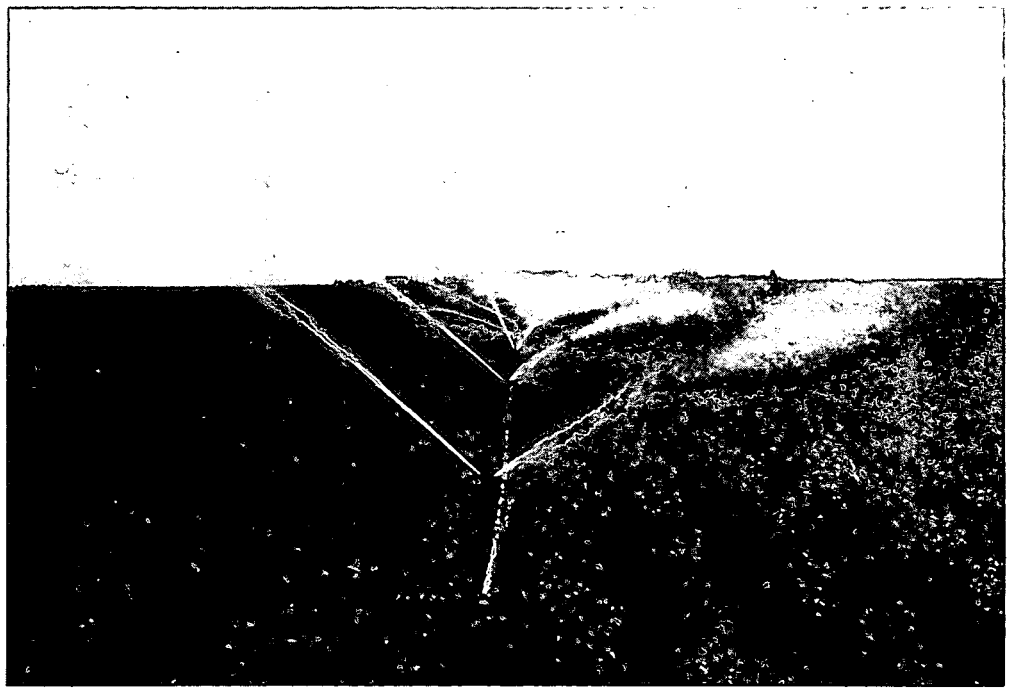
When the lateral reaches the last setting in the field, it will have to be moved back to the starting position -- the location of the first set.

To keep the sprinkler risers vertical during sprinkling and while the system is being moved, stabilizers are used on the lateral.

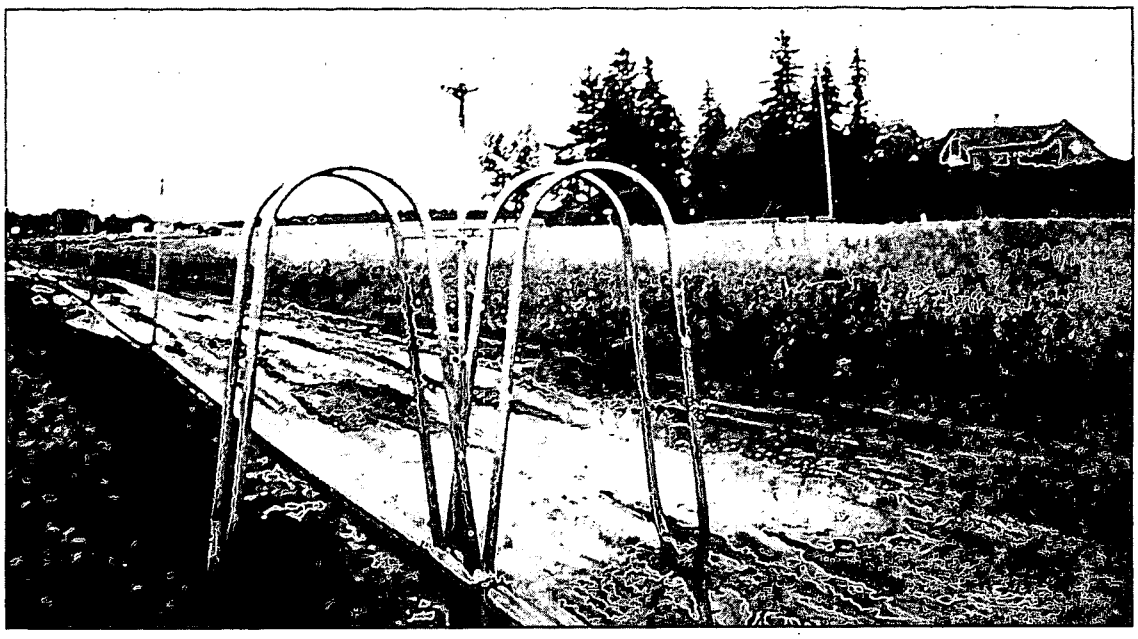
As the lateral is towed across the ground, pipe will wear, depending somewhat on the crop cover and soil texture. Sandy soils which have extremely rough particles will cause the greatest wear. Tow-line couplers usually provide for turning the pipe to distribute the wear around its circumference.

The turn strip may be grass, hay, or some harvestable crop so that this land is not completely lost to production.

Generally, design requirements are same as hand-move systems.



A set-type irrigation system operating



An end-tow lateral or tractor-move system

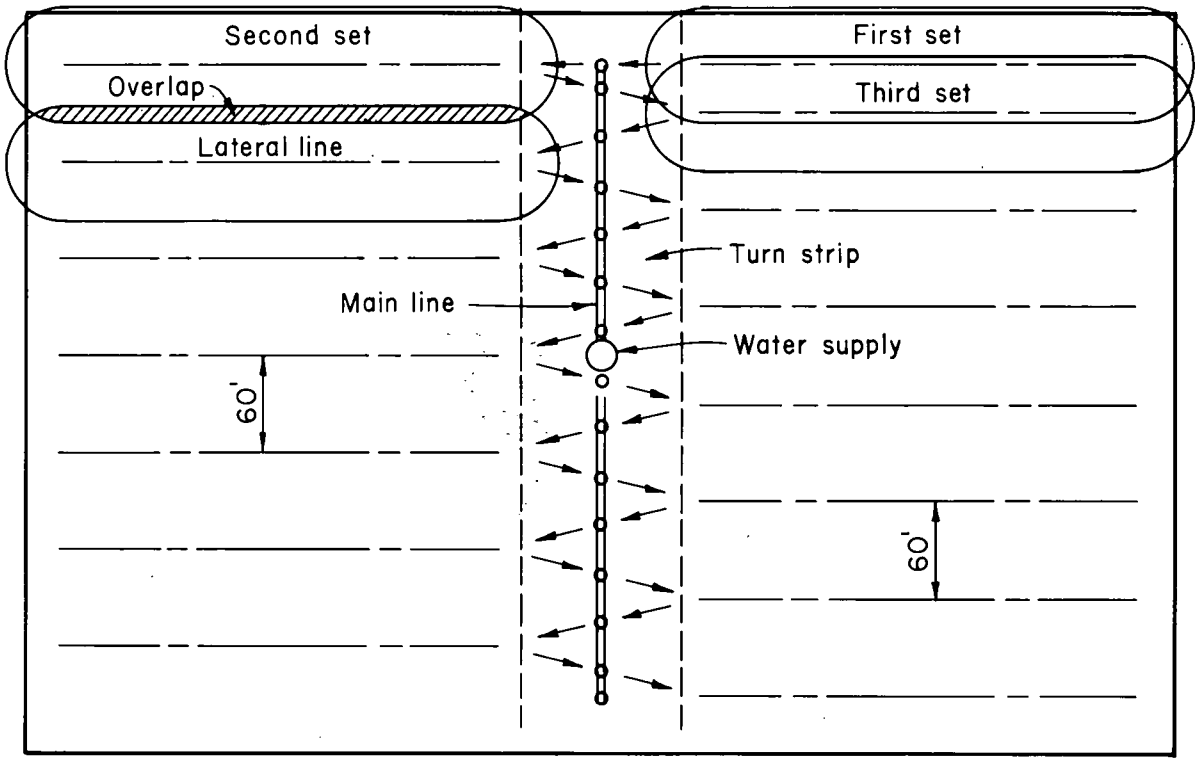


Figure 4-3. End-tow System Operation

Advantages and Limitations:

Rectangular fields desirable, requires 100 feet to 200 feet turnways and narrow alleyways in irrigated row crops. Adapted to any soil type that is suitable for sprinkler irrigation.

Rotating Boom

This system consists of pipe and nozzle arms that rotate about the center or balance point located on a 4-wheel mounted turntable. A tower and cable arrangement hold the booms in place. The booms rotate by water pressure, using a jet action controlled by various nozzle arrangements, nozzle sizes, and variable water pressures. The arms are provided in a choice of lengths providing coverage of about 1 to 4 acres per setting. Application rates vary from about 0.4 to 0.8 inch per hour with the usual rate being approximately 0.5 in. per hr. The unit can be pulled ahead to a new setting by a tractor attached to the boom carriage by a cable that is sufficiently long so that the tractor operates on dry ground. As the boom moves ahead, the feeder pipeline can be picked up and placed on the trailer that supports the boom. Settings should be such that a triangular pattern results with adjacent lanes.

Because of the large wetted diameter of coverage, there is some problem with wind distortion of the pattern. The long arms help keep this distortion from becoming too severe. However wind also affects rotation speed of the booms. When the boom arms are at right angles to the wind, rotation speed tends to slow. Under severe conditions, it may stop when it reaches a position at right angles to the wind. Since the water discharges from the nozzle at a uniform rate, any variation in rotation speed will upset the sprinkler's distribution pattern.

A rotating boom in operation

The distance between lanes should be equal to the diameter of the boom plus 70 per cent of the difference between the wetted diameter and the boom diameter.

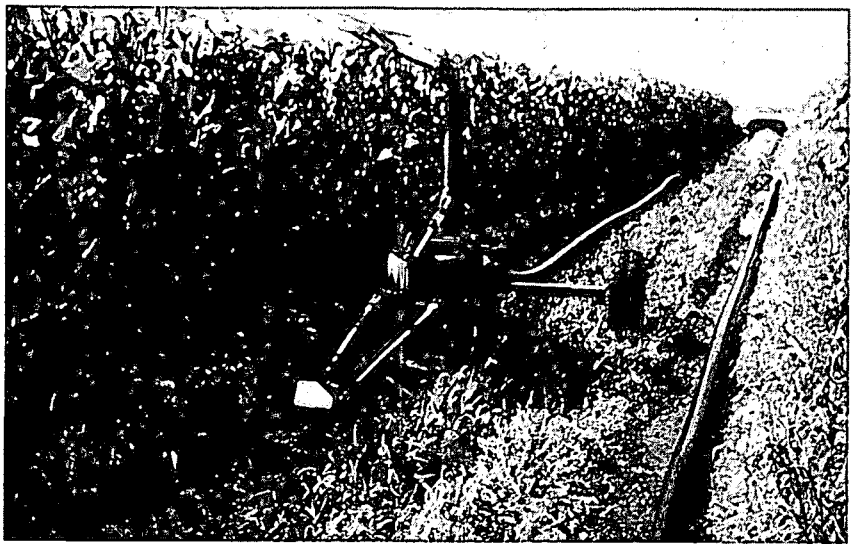
Advantages and Limitations

Rotating boom systems can be used on irregularly shaped fields. Wind affects rotation and water distribution. Requires alleyways for row crops. Application rate is too high for some soils.

Volume Gun

The volume gun sprinkler consists of a single high capacity nozzle mounted on a two- or four-wheel trailer. The pump and power unit may also be mounted on the equipment, or it may be permanently placed at a central location. In some types, a tractor is used as the power unit. Volume gun sprinklers require high operating pressures to provide a good break-up of the water discharged through the nozzle. The nozzles used on the hydraulic or giant sprinkler are usually larger than 3/4-inch diameter and recommended operating pressures usually exceeded 90 pounds per square inch. This pressure will increase the horsepower requirement for the distribution system. When the pressure of the volume gun is below manufacturer's recommendations, water distribution will be uneven.

The wetted diameters of both the boom and the volume gun are extremely large compared to the 10- to 15-gallon per minute sprinklers which are often used on lateral lines. Because of the large wetted diameter, it is difficult to obtain proper overlap of the sprinkler patterns. Wind distortion of the pattern is also a factor in trying to accomplish good field-wide water distribution. The distance between the lanes should be approximately 65 percent of the diameter of the wetted area. The sets should be such that a triangle pattern will result. This gives the best water distribution pattern.



A self-propelled volume gun

Advantages and Limitations

Volume guns can be used on irregularly shaped fields. Requires high operating pressures, wind affects water distribution. Requires alleyways for row crops. Have high application rates and, therefore, suited only to relatively high intake rate soils. Application rates generally are in excess of .65 inch per hour.

Continuous Move Sprinklers

Both the boom and the volume gun can be operated as continuous move sprinklers. With a flexible supply hose or open ditch to convey water and either a cable with a power winch or a slow moving tractor powered unit the sprinkler can operate as it moves along a lane.

The speed of sprinkler travel can be varied and is adjusted according to the amount of water to be applied. While the water discharge from the sprinkler nozzle is at a constant rate, the amount of irrigation water applied can be varied by the sprinkler travel rate. Slow sprinkler movement means a relatively large amount of water will be applied to the soil. The speed can also be adjusted so that moving the hose and sprinkler from one lane to the next will be a chore-time operation.

The flexible hose is available in 4-inch and 5-inch sizes. There is considerable friction loss in the hose which must be overcome by pump pressure. This additional pressure requires additional horsepower and increases the operating cost of the system.

In addition to having sufficient strength to withstand high operating pressures, the hose must be strong enough to be towed when full of water. Thus, a special type of hose is needed for the continuous move sprinklers. Wear and abrasion are also important considerations in the use of the hose. Since the hose is relatively high priced, periodic replacement is a sizeable maintenance cost and should be considered in the purchase of this type system. If water is supplied by an open ditch, seepage losses may be high and field slopes must be such that these ditches are practical to use.

Continuous Move Boom

Figure 4-4 shows the operation of a boom sprinkler with a continuous move. A winch is anchored at one end of the field and an air-cooled gasoline engine winds up the cable which tows the sprinkler at a continuous rate along the lane through the field. The flexible hose supplies water to the sprinkler from the mainline in the center of the field. For a lane length of 1,320 feet, about 600 feet of hose is required.

The distance between the lanes should be approximately equal to the diameter of the boom plus 70% of the difference between the wetted diameter and the boom diameter. Note however, that the overlap problem between adjacent sprinkler patterns in the lane is no longer present. Thus the total field distribution with the continuous move sprinkler

is considerably better than with a set type operation. The lane where the sprinkler as it moves through the field should not tilt one way or the other because of an uneven lane. This will cause an uneven water distribution pattern.

Design requirements are the same as shown for rotating boom.

Advantages and Limitations

Same as for rotating boom except rectangular fields are desirable and has high friction loss in flexible hose.

Continuous Move Volume Gun

The same type continuous move operation is used with the volume gun.

The power to move the sprinkler may be supplied by self-propelled equipment or by a motor mounted on the sprinkler trailer which winds a cable on a drum. The cable is then anchored at the end of the field. Another system has the motor and winch anchored at the end of the field.

On some types of volume gun sprinklers using the continuous move principle, a sprinkler mechanism purposely does not water the lane area directly in front of its travel to keep a firm track for the sprinkler cart or trailer.

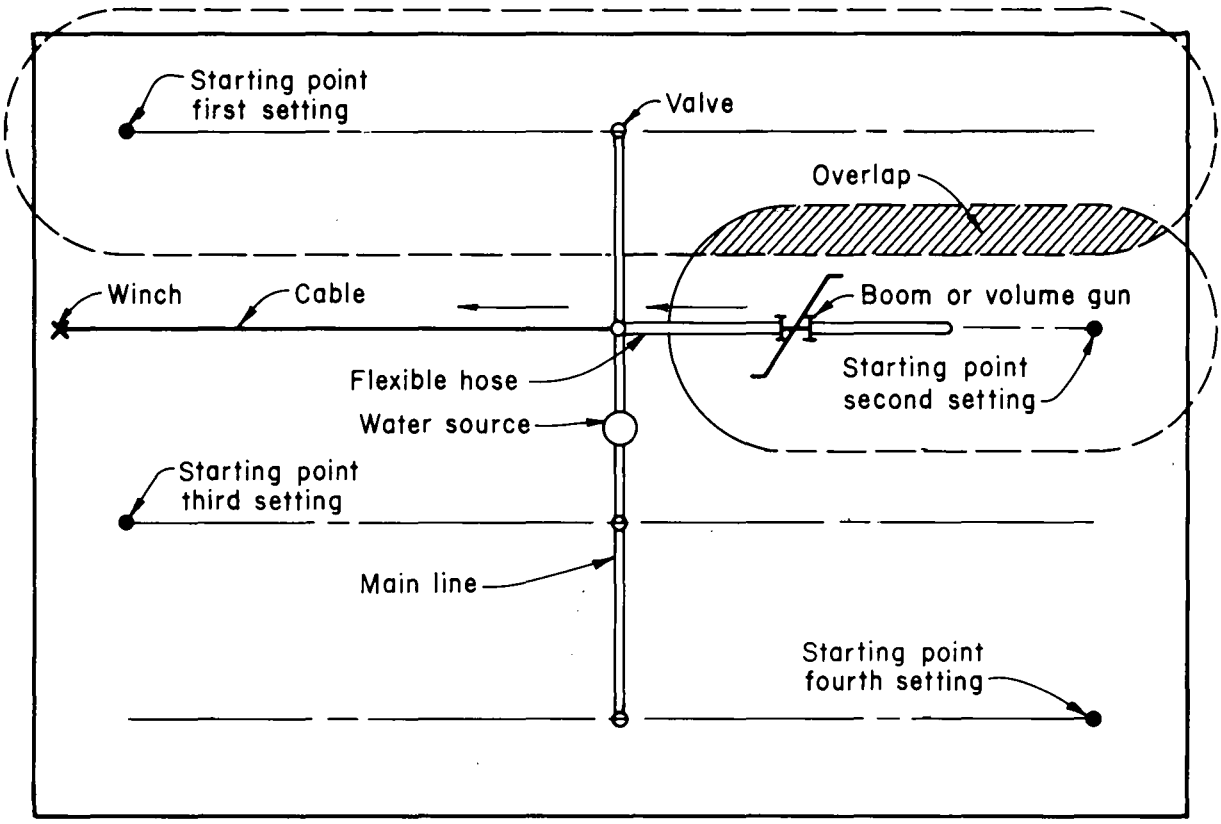


Figure 4-4. Continuous Move Boom or Volume Gun

As with the continuous move boom sprinkler, the overlap pattern between individual sets along the lane is eliminated, meaning the distribution pattern is better with a continuous move sprinkler than with the same sprinkler set at selected intervals.

Advantages and Limitations

Same as for volume gun except rectangular fields are desirable and high friction loss in flexible hose.

Center-Pivot, Self-Propelled Sprinkler

This system consists of a single lateral amounted on wheels spaced on approximately 100 ft. centers and supported by towers or bridge truss. Each of the towers has a device to provide power to the wheels. The type of power varies with the manufacturer. It can be provided by the water being pumped through the system, by hydraulic oil, by an electric motor on each tower, by compressed air, or by revolving water jets.

The operation of the center-pivot, self-propelled sprinkler is shown in figure 4-5. An anchored pivot point is located at the center of the field around which the entire system pivots.

The speed of rotation of the center-pivot system may vary from 12 hours to 120 hours per revolution. With the center-pivot, self-propelled system the rate of water application is the same regardless of the speed of rotation. However, the faster the rotation speed, the less total water applied per rotation. An average rotation speed is approximately 60 to 72 hours per revolution. An average water application is approximately 1.0 inch.

The speed of the center-pivot, self-propelled sprinkler is usually controlled by the end tower, called the master tower. A system of alignment controls keep the other towers in line with the end tower.

With the center-pivot, self-propelled system, a circular or square field is required. On a quarter section, 160 acres, approximately 135 acres is under irrigation. About 6 acres in each corner of the field will not be irrigated.

Advantages and Limitations

Requires circular or square fields with no obstructions. Application rate is high at outer end of line resulting in excess runoff on low intake soils. Required operating pressure varies from 65 to 75 pounds per square inch at the pivot depending on system length and lateral pipe sizes. There is a tendency for wheels to cut deep ruts in some soils.

Most center pivot systems use a large gun to fill in parts of the corners of a square field. The area covered by the big gun seldom receives as much water as the remainder of the field and generally this is the area producing the poorest yields.

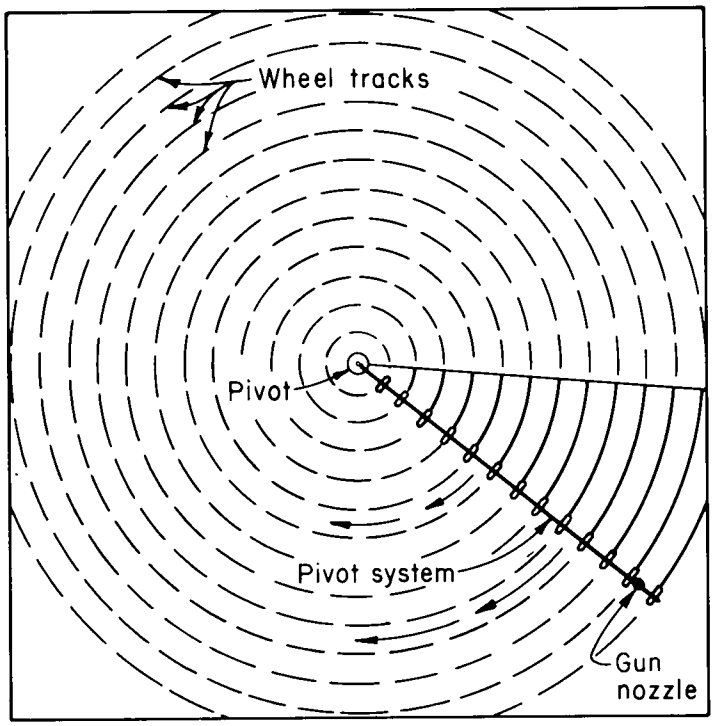
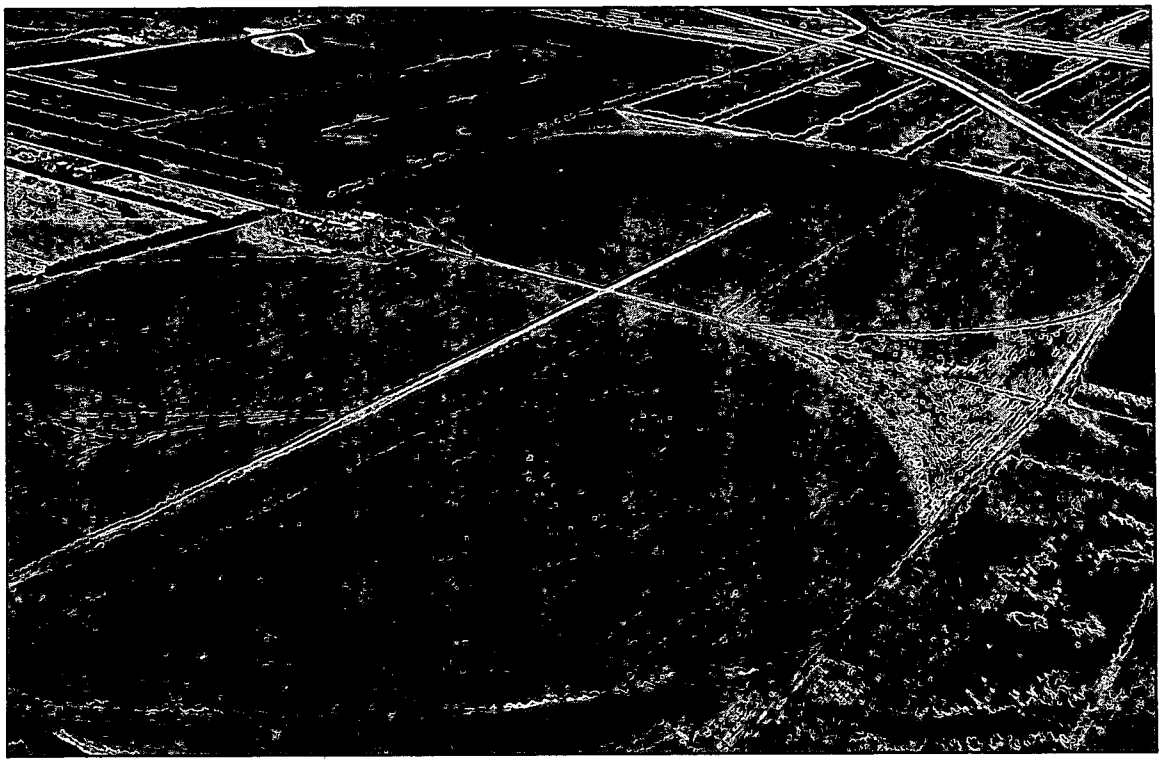
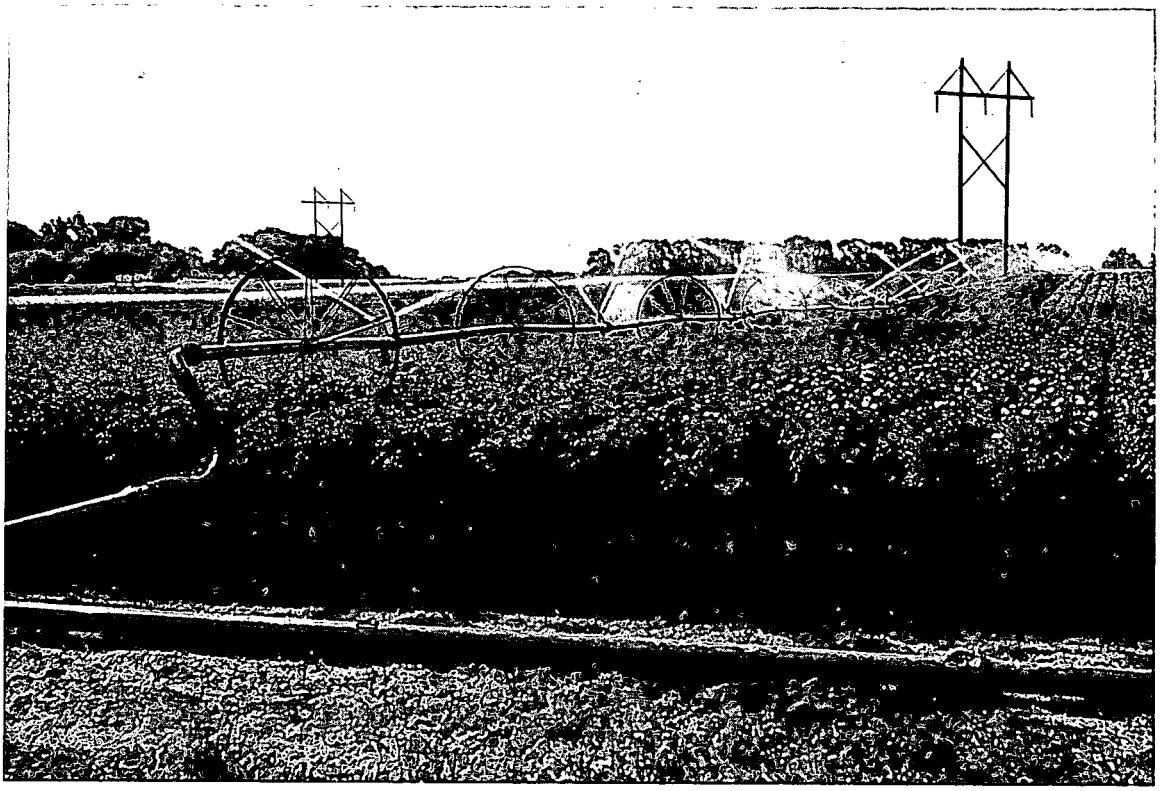


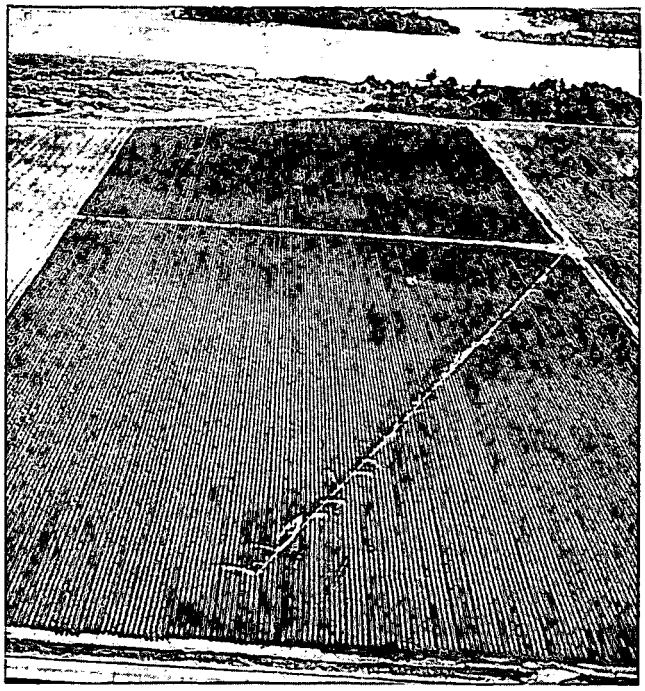
Figure 4-5. Center Pivot. (Gun Nozzle Used in Corners Only)



Aerial view of two center pivot systems



A side roll system operating



Center pivot system operating

Solid Set

The solid set system is rapidly becoming more popular, particularly for high value crops. With this system, the mainline and the lateral lines remain in place during the growing season. Sometimes the solid set system is permanent with the mainline and lateral lines buried. With other solid set systems, the pipes are installed in the field after planting and remain there until harvest.

These systems may be used to apply water to meet crop demands or for the purpose of temperature modification or for frost protection.

Advantages and Limitations

Adapted to irregularly shaped fields. High investment costs. Lateral lines may interfere with field operations.

There are two types of solid set systems:

(1) Where all the laterals are operated simultaneously. This type of system or a rapid sequence system where water is applied for approximately 3 minutes during each 15 minute interval is required for temperature modification. For complete frost control the solid set system is required. Figure 4-6 shows this type of sprinkler.

(2) The Sequa-Matic system where a group of sprinklers are operated the required time then automatically shut off and another group turned on, this sequence is repeated until the field is irrigated. This type is shown in figure 4-7.

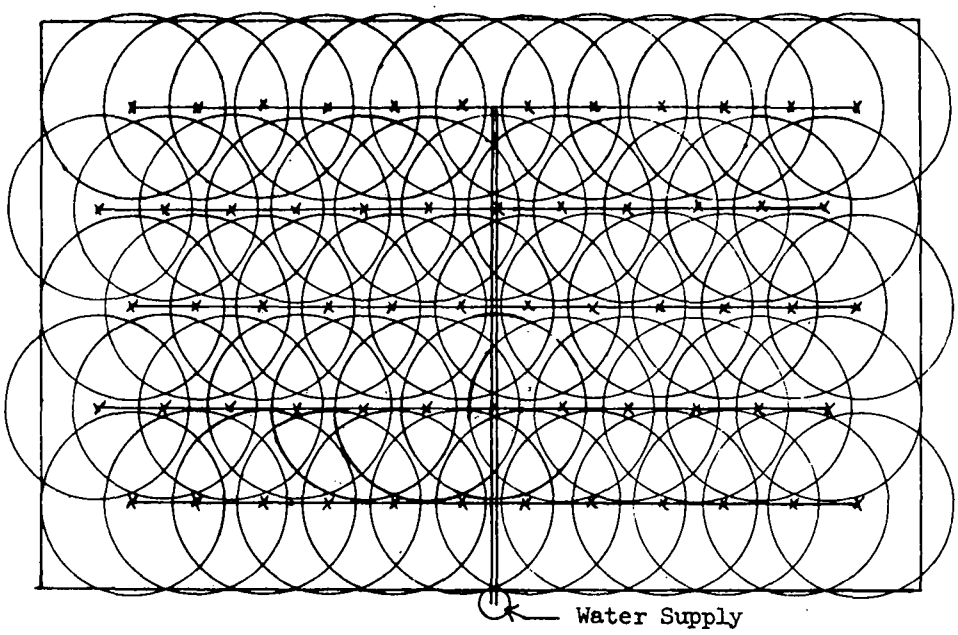


Figure 4-6 A solid set system

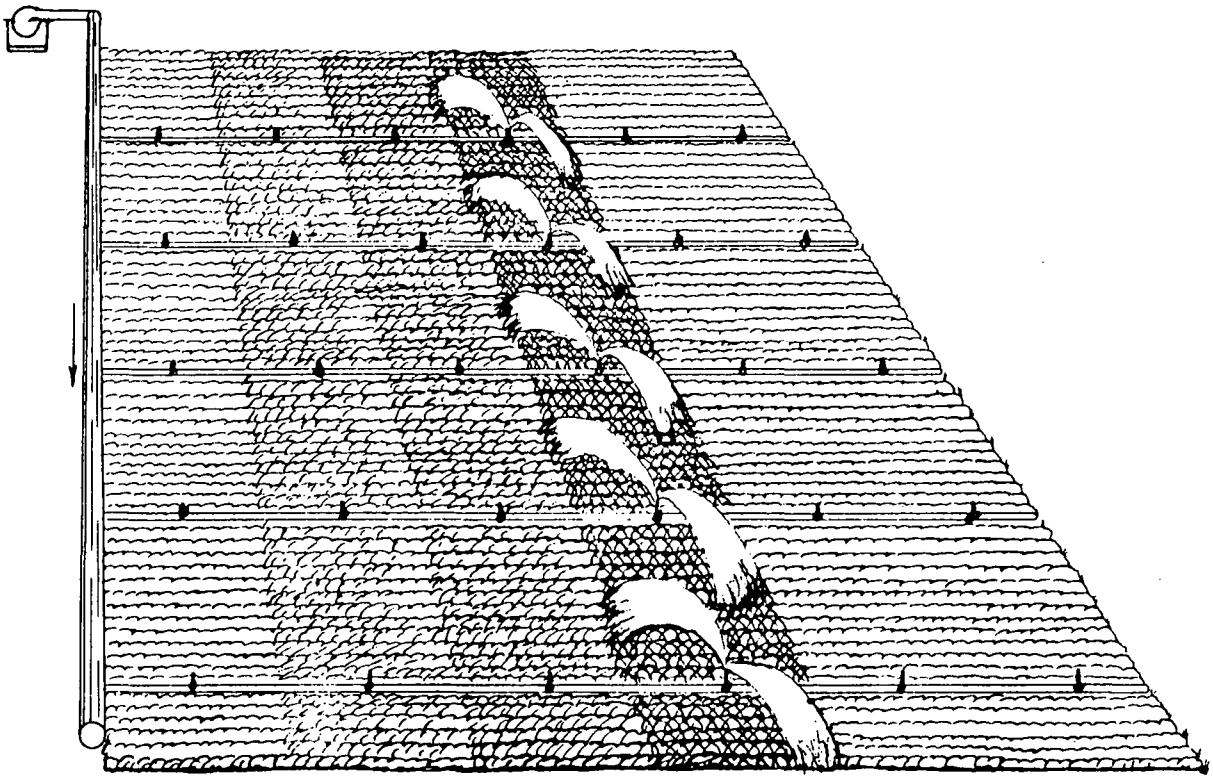


Figure 4-7 Sequencing solid set

Capacity Requirements

The required capacity of a sprinkler system depends on the size of the area irrigated (design area), the gross depth of water applied at each irrigation, and the net operating time allowed to apply this depth.

The capacity of a system may be computed by the formula

$$Q = \frac{453\ Ad}{FH}$$

where Q = discharge capacity in gallons per minute
A = acreage of the design area
d = gross depth of application in acre-inches per acre
F = number of days allowed for completion of one irrigation
H = number of actual operating hours per day

F and H are of major importance in that they have a direct bearing on the capital investment per acre required for equipment. From the formula, it is obvious that the greater the product of these factors (operating time) the smaller the system capacity (and thereby the cost) will be for a given acreage. Conversely, where the operator wishes to irrigate his acreage in a minimum number of days and has labor available

only for operation during daylight hours, his equipment costs per acre will be higher.

Before a sprinkler system is planned, the planner should thoroughly acquaint the owner with these facts and should have a clear understanding with him on the number of operating hours that can be allowed for completing one irrigation. Available labor with a minimum of interference with other farming operations must always be considered.

The acreage discharge chart (figure 4-8) may be used for the solution of this formula.

Figure 4-9 may be used to plan or evaluate center pivot systems in relation to wetted radius, area, water supply, gross application depth, and number of days allowed for completion of one irrigation (irrigation period).

Power Requirements

The power for pumping irrigation water may be provided by electric motor or internal combustion engines. Whatever the type of motor used, the horsepower rating depends upon the total dynamic head (total static head plus friction losses in pipe, fittings, and valves, velocity head at end of discharge pipe, and pressure to operate lateral(s)), rate of discharge, pump efficiency and drive efficiency. Figure 4-10 is a sketch of factors to consider in calculating total dynamic head. Refer to SCS National Engineering Handbook, Section 15, for design values of head loss in pipes and fittings.

The useful work done by a pump is called the water horsepower and is expressed by the following relationship:

$$\text{w.h.p.} = \frac{\text{gpm x t.d.h.}}{3{,}960}$$

This represents the power to drive the pump if the pump and drive were 100 percent efficient.

The term brake horsepower (b.h.p.) is the output rating at the drive shaft of the power unit. It accounts for the less than 100 percent efficiency of the pump and drive. Brake horsepower is given by the following equation:

$$\text{b.h.p.} = \frac{\text{gpm x t.d.h.}}{3{,}960 \times E_p \times E_d}$$

Caution must be exercised when making recommendations relating to b.h.p. Irrigation engines are commonly rated in terms of continuous b.h.p. Tractor engines are not rated in continuous b.h.p.

A direct drive mechanism will have an efficiency of 100 percent. A V-belt drive may be about 90 percent and a 90° gear head will be 95 percent. A figure of 80 percent should be used for planning a flat-beltdrive.

Example: Given a system which requires 500 gpm, the t.d.h. is 150 feet. The pump efficiency is 75 percent and the V-belt drive is 90 percent efficient. Find the b.h.p.

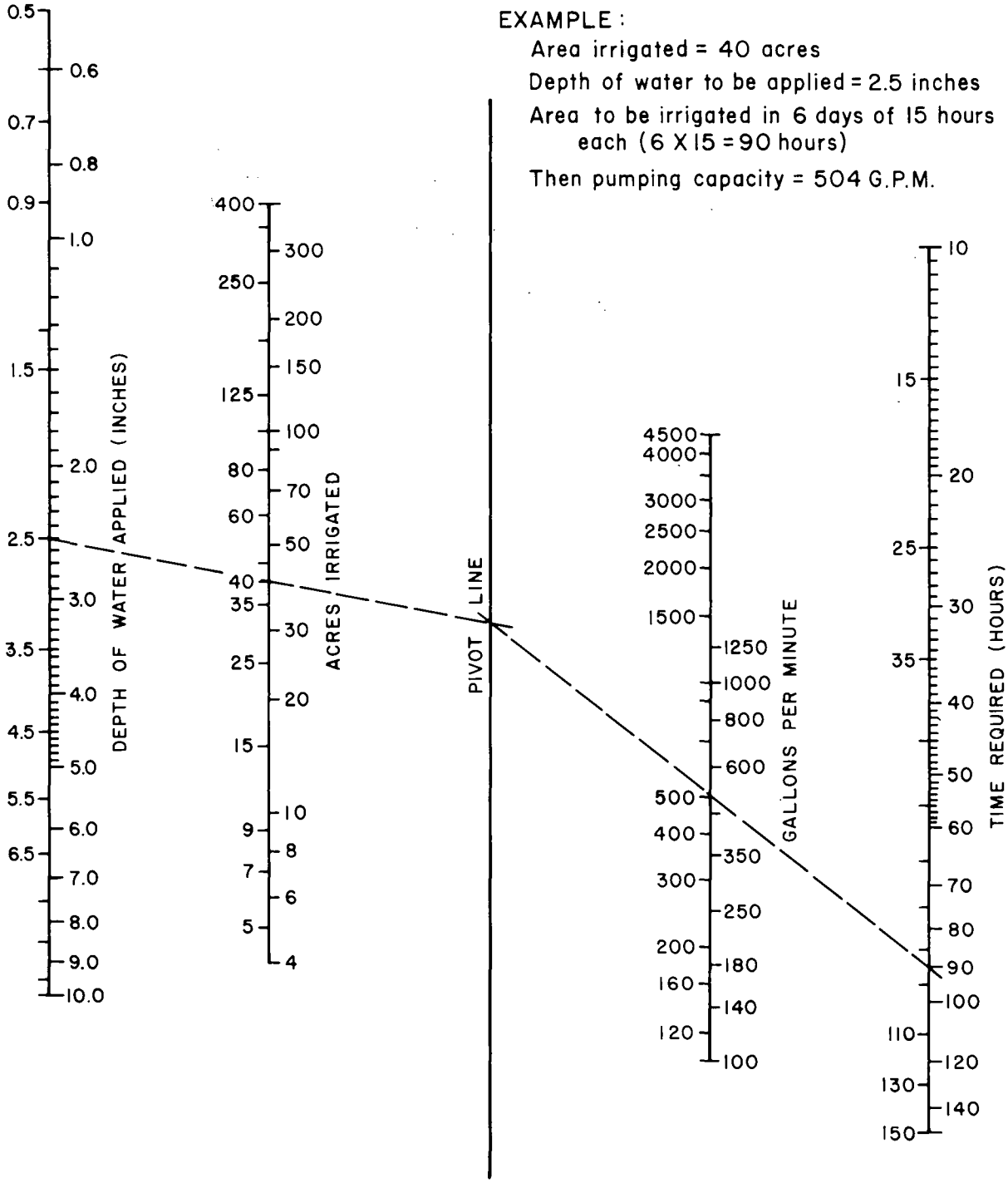
$$\text{b.h.p.} = \frac{500 \times 150}{3{,}960 \times .75 \times .90}$$

$$\text{b.h.p.} = 28.06$$

If operating costs are to be computed, the power input to the motor must be considered. The input is found by dividing the b.h.p. by the motor efficiency. In the case where an electric motor is used, the power input in terms of kilowatt-hours per acre-foot pumped is given by:

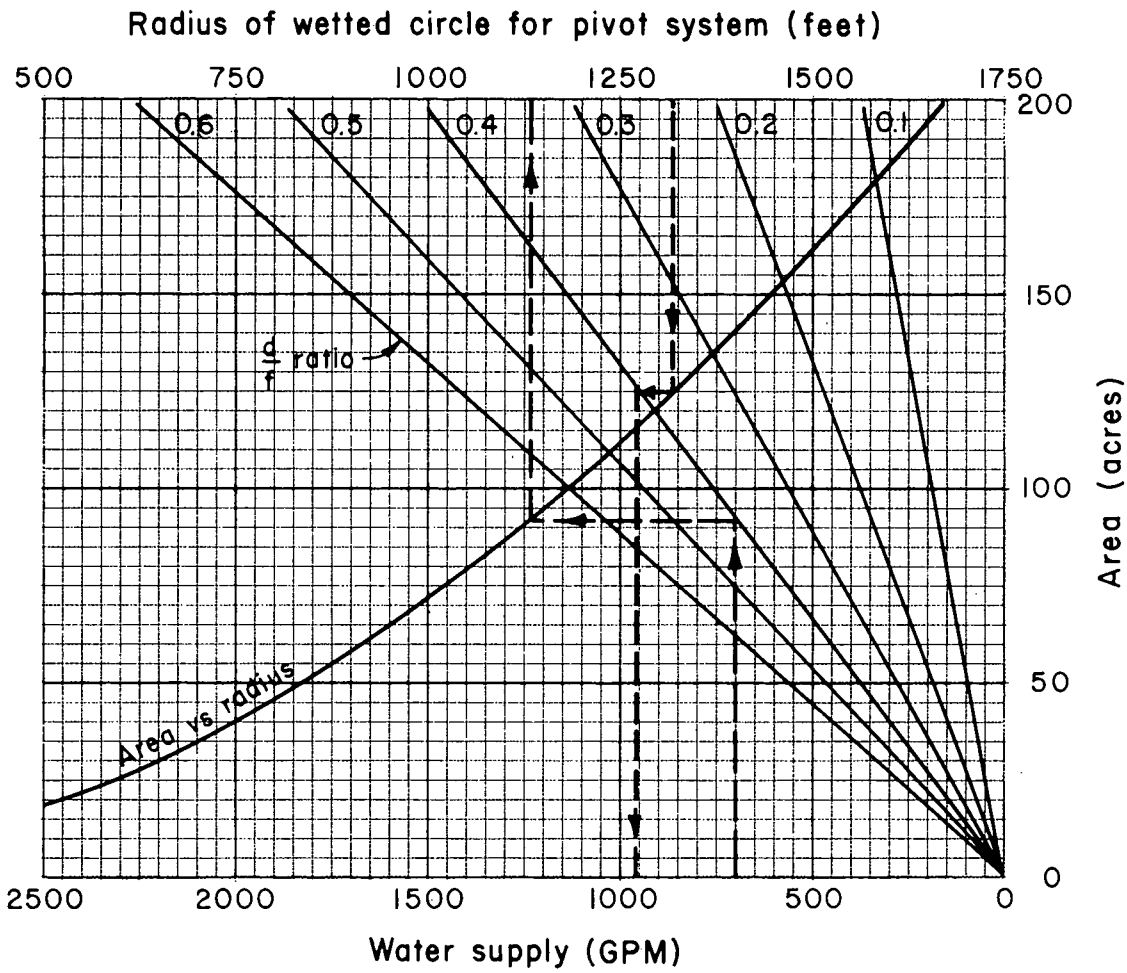
$$\text{Kw-hr/acre-ft.} = \frac{1{,}024 \times \text{t.d.h.}}{\text{Ep} \times \text{Ed} \times \text{Em}}$$

$$\text{Gallons per minute, } Q = \frac{453 \times \text{Acres irrigated (A)} \times \text{Depth of water applied (d)}}{\text{Number of days (F)} \times \text{Hours per day (H)}}$$



Reference:
Agricultural Engineering, July 1951

Figure 4-8. Capacity Requirements For Irrigation Systems.



Rules For Use of Chart

1) Reading up--from known water supply read vertically to d/f line; move horizontally to area vs. radius curve; then vertically to find radius.

2) Reading down--from known system length drop vertically to area vs. radius curve; move horizontally to appropriate d/f line; then drop vertically to water supply.

Example

1) Given: Water supply is 700 GPM crop requirements are 2.0 inches with a 5 day irrigation period.

Find maximum acreage that can be adequately irrigated. Also find center pivot radius associated with this acreage.

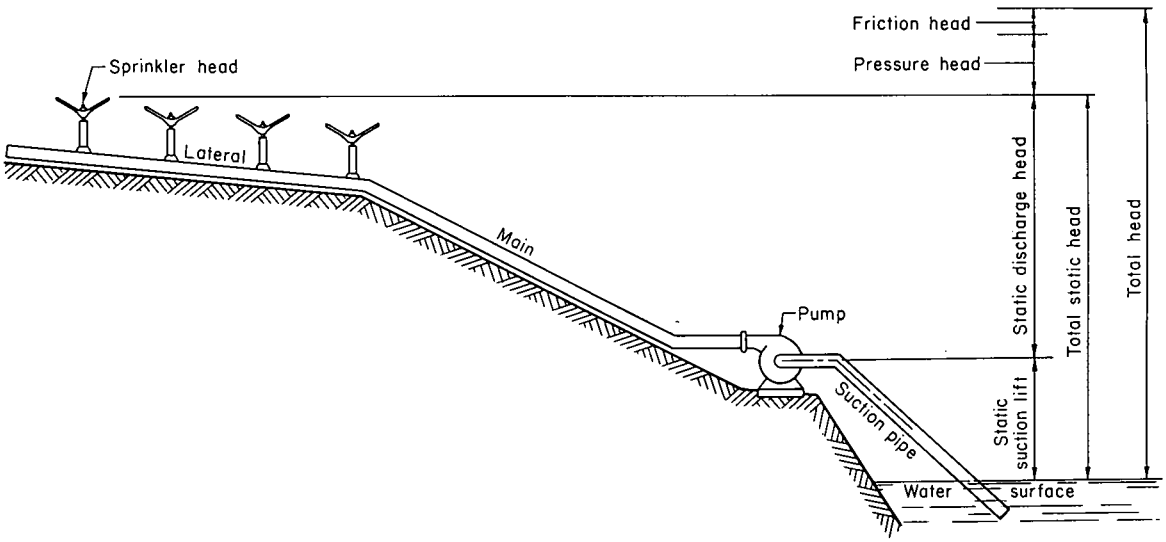
Solution: $d/f = \frac{2.0}{5.0} = 0.4$; Enter 700 GPM; apply rule 1; find area is about 90 acres and system radius is about 1,130 feet.

2) Given: Center Pivot length of 1,320 feet; crop needs 2.4 in. (gross) in 6 days (irrigation period); d/f = 0.4

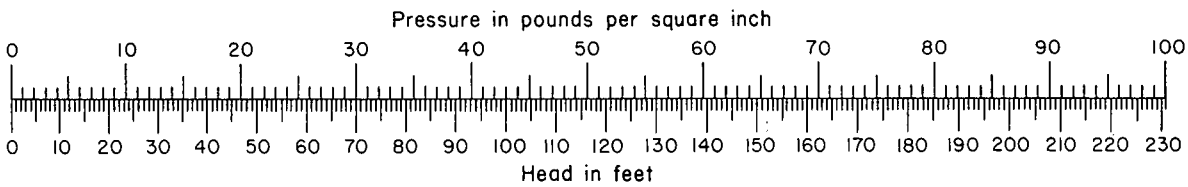
Find water supply required.

Solution: Apply rule 2; find 950 GPM required.

Figure 4-9 Capacity Requirements for Center Pivot Systems



ELEMENTS OF A PUMP AND POWER UNIT ON A SPRINKLER SYSTEM AND THE CORRESPONDING ELEMENTS OF "TOTAL HEAD" USED IN CALCULATING POWER REQUIREMENTS



SCALE FOR CONVERTING UNITS OF HEAD AND PRESSURE

1. Pressure head is the average operating pressure for the lateral.

2. Friction head is pressure loss due to friction in the main, lateral, suction pipe, and fittings.

3. Static discharge head is the difference in elevation between the centerline of the discharge pipe and the elevation of the sprinkler orifice.

4. Static suction head (lift) is the difference in elevation between the water surface elevation being pumped and the centerline of the discharge pipe.

Figure 4-10 Illustration of Total Dynamic Head With Conversion Scale of Head and Pressure

TABLE 4-1

CENTER-PIVOT IRRIGATION SYSTEMS

% of Water Applied in Last 100 Ft. 1/	Total System Length (in feet) 2/	Total Area of Square Field Twice Length of System (in acres)	Area Covered in Acres 3/	
			With Gun Sprinkler Used Only In Corners	With Gun Sprinkler Used on Entire Circle
36.0	500	23.0	22.0	26.0
33.1	550	27.8	26.2	30.5
30.6	600	33.1	30.8	35.3
28.4	650	38.8	36.0	40.6
26.5	700	45.0	41.3	46.1
24.8	750	51.8	47.2	52.1
23.4	800	58.8	53.3	58.4
22.1	850	66.3	59.8	65.0
21.0	900	74.5	66.7	72.2
20.0	950	82.9	74.0	79.5
19.0	1000	91.8	81.7	87.4
18.1	1050	101.3	89.5	95.3
17.3	1100	111.0	98.0	104.0
16.6	1150	121.3	106.6	112.6
16.0	1200	132.2	115.7	121.9
15.4	1250	143.3	123.8	130.0
14.8	1300	155.0	134.0	141.3
14.3	1350	167.3	145.0	151.6
13.8	1400	179.8	155.2	162.0
13.3	1450	193.0	166.5	173.2
12.9	1500	206.0	177.7	184.7

1/ Less volume of end gun when used.

2/ Generally outside drive wheel approximately 50 ft. from end.

3/ Based on 100 ft. gun coverage.

EXAMPLE: System is 900 feet long. Then 21 percent of water is applied in last 100 feet. 66.7 acres are covered with gun used in corners only.

TABLE 4-2

CENTER PIVOT SYSTEMS

PERCENT OF WATER APPLIED IN EACH SECTION

(Exclusive of Big Gun)

System Length	Distance from Pivot in 100 Foot Sections														
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15
500	4.0	12.0	20.0	28.0	36.0	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
600	2.8	8.3	13.9	19.4	25.0	30.6	- -	- -	- -	- -	- -	- -	- -	- -	- -
700	2.0	6.1	10.2	14.3	18.4	22.5	26.5	- -	- -	- -	- -	- -	- -	- -	- -
800	1.6	4.7	7.8	10.9	14.1	17.2	20.3	23.4	- -	- -	- -	- -	- -	- -	- -
900	1.2	3.7	6.2	8.6	11.1	13.6	16.1	18.5	21.0	- -	- -	- -	- -	- -	- -
1,000	1.0	3.0	5.0	7.0	9.0	11.0	13.0	15.0	17.0	19.0	- -	- -	- -	- -	- -
1,100	0.8	2.5	4.1	5.8	7.4	9.1	10.8	12.4	14.1	15.7	17.3	- -	- -	- -	- -
1,200	0.7	2.1	3.5	4.9	6.2	7.6	9.0	10.4	11.8	13.2	14.6	16.0	- -	- -	- -
1,300	0.6	1.8	3.0	4.1	5.3	6.5	7.7	8.9	10.1	11.2	12.4	13.6	14.8	- -	- -
1,400	0.5	1.5	2.5	3.6	4.6	5.6	6.6	7.7	8.7	9.7	10.7	11.7	12.8	13.8	- -
1,500	0.4	1.3	2.2	3.1	4.0	4.9	5.8	6.7	7.6	8.5	9.3	10.2	11.1	12.0	12.9

TABLE 4-3

NOZZLE DISCHARGE GPM AND AVERAGE
WETTED DIAMETER FOR SPRINKLER NOZZLES

*60' *70'

	Nozzle Size	NOZZLE PRESSURE #/SQ.IN. 25	30	35	40	45	50	55	60	65	70	75	
	3/32	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0				
	7/64	1.7	1.9	2.0	2.2	2.3	2.4	2.6	2.7				
*70'	1/8	2.2	2.4	2.6	2.8	3.0	3.2	3.3	3.5	3.6			*80'
	9/64	2.9	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6			
	5/32	3.5	3.9	4.2	4.5	4.7	5.0	5.2	5.5	5.7	5.9		*90'
*80'	11/64	4.3	4.7	5.1	5.4	5.7	6.0	6.3	6.6	6.8	7.1		
	3/16	5.0	5.5	6.0	6.4	6.8	7.2	7.5	7.8	8.1	8.4	8.7	
*90'	13/64	5.9	6.5	7.1	7.6	8.1	8.5	8.9	9.2	9.5	9.8	10.2	*100'
	7/32	6.8	7.6	8.3	8.9	9.4	9.9	10.3	10.7	11.2	11.6	12.0	*110'
	1/4		9.9	10.7	11.4	12.1	12.8	13.5	14.1	14.8	15.4	16.0	
*100'	9/32		12.4	13.4	14.3	15.2	16.1	17.0	17.9	18.7	19.5	20.3	*125'
*110'	5/16		15.2	16.5	17.7	18.9	20.0	21.0	22.0	23.0	23.9	24.8	
	11/32			19.7	21.1	22.4	23.6	24.8	25.9	27.0	28.1	29.2	*145'
	3/8	*125'		22.8	24.4	26.0	27.6	29.2	30.6	32.0	33.3	34.5	
	13/32			27.2	29.1	30.9	32.7	34.3	35.9	37.4	38.9	40.3	
	7/16	*145'			33.9	35.9	37.8	39.7	41.5	43.3	45.1	46.8	*165'
	15/32				38.9	41.1	43.3	45.4	47.4	49.4	51.4	53.3	
	1/2	*165'			43/6	46.0	48.4	50.7	53.0	55.3	57.5	59.6	*185'
	17/32					51.6	54.0	56.4	58.8	61.2	63.5	65.8	
	9/16	*185'				57.5	60.6	63.6	66.5	69.4	72.2	74.9	*205'
	5/8					70.7	73.6	77.2	80.8	84.4	87.8	91.0	

* Approximate diameter of coverage.

For a sprinkler head with 2 different nozzles, the wetted diameter is coverage of the larger nozzle. Unshaded area is approximate pressure recommended for best distribution. Check Mfg. catalog for specific nozzle characteristics.

TABLE 4-4
DESIGN DATA OF TYPICAL SPRINKLERS

B preceding nozzle number refers to Buckner nozzles

Pressure at Base of Sprinkler psi	B 180G						B 180GE and 180GSE					
	Nozzle 5/32"		Nozzle* 11/64"		Nozzle 3/16"		Nozzle 5/32"		Nozzle* 11/64"		Nozzle 3/16"	
	Dia.	GPM	Dia.	GPM	Dia.	GPM	Dia.	GPM	Dia.	GPM	Dia.	GPM
50	90	5.0	95	6.0	100	7.2	98	5.0	100	6.0	106	7.2
55	91	5.2	96	6.3	101	7.5	100	5.2	102	6.3	108	7.5
60	92	5.4	97	6.6	102	7.8	101	5.4	103	6.6	109	7.8
65	93	5.7	98	6.8	103	8.1	102	5.7	104	6.8	110	8.2
70	94	5.9	99	7.1	104	8.5	103	5.9	106	7.1	111	8.5

Pressure at Base of Sprinkler psi	B 8600GE						B 8602GE					
	Nozzle 7/32"		Nozzle* 1/4"		Nozzle 9/32"		Nozzle 3/16"		Nozzle* 7/32"		Nozzle 1/4"	
	Dia.	GPM	Dia.	GPM	Dia.	GPM	Dia.	GPM	Dia.	GPM	Dia.	GPM
50	115	9.6	120	12.5	125	15.8	105	7.0	115	9.6	120	12.5
55	117	10.1	122	13.2	127	16.6	107	7.3	117	10.1	122	13.2
60	120	10.5	125	13.8	130	17.4	110	7.7	120	10.5	125	13.8
65	122	11.0	127	14.4	132	18.2	112	8.0	122	11.0	127	14.4
70	125	11.4	130	14.9	135	18.9	115	8.3	125	11.4	130	14.9

RB preceding nozzle number refers to Rainbird nozzles

Pressure at Base of Sprinkler psi	RB 30W						RB 40BW					
	Nozzle 5/32"		Nozzle* 11/64"		Nozzle 3/16"		Nozzle 11/64"		Nozzle* 3/16"		Nozzle 13/64"	
	Dia.	GPM	Dia.	GPM	Dia.	GPM	Dia.	GPM	Dia.	GPM	Dia.	GPM
45	89	4.7	93	5.7	98	6.8	98	5.7	102	6.8	105	8.1
50	90	5.0	95	6.0	100	7.2	100	6.0	104	7.2	107	8.5
55	91	5.2	96	6.3	101	7.5	101	6.3	106	7.5	109	8.9
60	92	5.4	97	6.6	102	7.8	102	6.6	107	7.8	110	9.2
65	93	5.7	98	6.8	103	8.2						
70	94	5.9	99	7.1	104	8.5						

Pressure at Base of Sprinkler psi	RB 14070W						RB 70 EW					
	Nozzle 11/64"		Nozzle* 3/16"		Nozzle 13/64"		Nozzle 7/32"		Nozzle* 1/4"		Nozzle 9/32"	
	Dia.	GPM	Dia.	GPM	Dia.	GPM	Dia.	GPM	Dia.	GPM	Dia.	GPM
45	105	5.7	108	6.8	111	8.1	123	19.4	131	12.2	134	15.5
50	106	6.0	109	7.2	113	8.5	125	19.9	134	12.9	138	16.3
55	107	6.3	110	7.5	115	8.9	127	10.4	136	13.6	141	17.2
60	108	6.6	111	7.8	116	9.2	129	10.9	139	14.2	144	18.0
65	109	6.8	112	8.2	117	9.5	131	11.4	142	14.8	147	18.8
70	110	7.1	113	8.5	118	9.8	134	11.8	145	15.4	150	19.5

* Indicates standard nozzle size

TABLE 4-5
DESIGN FIELD EFFICIENCIES FOR SPRINKLER SYSTEMS

Systems Requiring Scheduled Moves			
Net Irrigation Application	Sprinkler Application Rate (Inches per Hour)		
	<0.3	0.3 to 0.5	Over 0.5
< 2.0	.55	.60	.65
2.0 to 2.9	.60	.65	.70
3.0 or over	.65	.70	.75
Solid Set Systems and Systems Using Continuous Moving Laterals			
Net Irrigation Application	Sprinkler Application Rate (Inches per Hour)		
	<0.3	0.3 to 0.5	Over 0.5
<1.0	.60	.65	.70
1.0 to 1.9	.65	.70	.75
2.0 or over	.70	.75	.80

TABLE 4-6
SPRINKLER APPLICATION RATE

Appl. Rate In./Hr.	Application Per Lateral Set		
	7 Hr.	11 Hr.	23 Hr.
.18	1.26	1.98	4.14
.20	1.40	2.20	4.60
.22	1.54	2.42	5.06
.24	1.68	2.64	5.52
.26	1.82	2.86	5.98
.28	1.96	3.08	6.44
.30	2.10	3.30	6.90
.32	2.24	3.52	7.36
.34	2.38	3.74	7.82
.36	2.52	3.96	8.28
.38	2.66	4.18	8.74
.40	2.80	4.40	9.20
.42	2.94	4.62	9.66
.44	3.08	4,84	10.12
.46	3.22	5.06	-
.48	3.36	5.28	-
.50	3.50	5.50	-
.52	3.64	5.72	-
.54	3.78	5.94	-
.56	3.92	6.16	-
.58	4.06	6.38	-
.60	4.20	4.60	-
.62	4.34	6.82	-
.64	4.48	7.04	-
.66	4.62	7.26	-
.68	4.76	7.48	-
.70	4.80	7.70	-
.75	5.25	8.25	-
.80	5.60	8.80	-

TABLE 4-7
FRICTION LOSS IN FEET PER 100 FEET IN LATERAL LINES OF PORTABLE ALUMINUM PIPE WITH COUPLINGS

(Based on Scobey's formula and 30-foot pipe lengths)[1/]

Flow (gpm)	2-inch[2/] K_s = .34	3-inch[2/] K_s = .33	4-inch[2/] K_s = .32	5-inch[2/] K_s = .32	6-inch[2/] K_s = .32
100	25.4	3.20	0.738	0.244	0.099
120		4.54	1.04	.339	.140
140		6.09	1.40	.454	.188
160		7.85	1.80	.590	.242
180		9.82	2.26	.733	.302
200		12.0	2.76	.896	.370
220		14.4	3.30	1.07	.443
240		16.9	3.90	1.26	.522
260		19.7	4.54	1.47	.608
280		22.8	5.22	1.70	.700
300		25.9	5.96	1.93	.798
320		29.3	6.74	2.18	.904
340		32.8	7.56	2.45	1.02
360		36.6	8.40	2.74	1.13
380		40.6	9.36	3.03	1.26
400		44.7	10.3	3.34	1.38
420			11.3	3.66	1.51
440			12.3	4.00	1.66
460			13.4	4.35	1.80
480			14.6	4.72	1.95
500			15.8	5.10	2.12
550			18.9	6.12	2.52
600			22.2	7.22	2.98
650			25.9	8.40	3.46
700			29.8	9.68	3.99
750			33.8	11.0	4.54
800				12.5	5.15
850				14.0	5.78
900				15.6	6.44

1/ For 20-foot pipe lengths, increase values in the table by 7.0 percent. For 40-foot lengths, decrease values by 3.0%.

2/ Outside diameter.

TABLE 4-8

CORRECTION FACTOR FOR MULTIPLE OUTLETS 1/

Outlets (number)	Value of F
1	1.000
2	0.634
3	.528
4	.480
5	.451
6	.433
7	.419
8	.410
9	.402
10	.396
11	.392
12	.388
13	.384
14	.381
15	.379
16	.377
17	.375
18	.373
19	.372
20	.370
21	.369
22	.368
23	.367
24	.366
25	.365
26	.364
27	.364
28	.363
29	.363
30	.362
Over 30	.360

1/ To be used in conjunction with Table 4-6

Table 4-9--Friction loss in feet per 100 feet in main lines of portable aluminum pipe with couplings

(Based on Scobey's formula (K_s = .40) and 30-foot pipe lengths)[1]

Flow (gallons per minute)	3-inch[2] (2.914)	4-inch[2] (3.914)	5-inch[2] (4.896)	6-inch[2] (5.884)	7-inch[2] (6.872)	8-inch[2] (7.856)	10-inch[2] (9.818)
40	0.658	0.157					
50	1.006	.239					
60	1.423	.339					
70	1.906	.449	0.150				
80	2.457	.584	.193				
90	3.073	.731	.242				
100	3.754	.893	.295	0.120			
120	5.307	1.263	.417	.170			
140	7.113	1.693	.560	.227			
160	9.169	2.182	.721	.293			
180	11.47	2.729	.967	.366			
200	14.01	3.333	1.102	.448	0.209		
220	16.79	3.996	1.321	.537	.251		
240	19.81	4.713	1.558	.633	.296		
260	23.06	5.488	1.814	.737	.344		
280	26.55	6.316	2.089	.849	.397		
300	30.27	7.203	2.381	.967	.452	0.235	
320	34.22	8.142	2.692	1.094	.511	.265	
340	38.39	9.137	3.020	1.227	.573	.298	
360	42.80	10.18	3.366	1.368	.639	.332	
380	47.43	11.29	3.731	1.516	.708	.368	
400	52.28	12.44	4.113	1.671	.781	.399	0.136
420		13.65	4.513	1.833	.857	.445	.149
440		14.57	4.930	1.988	.936	.486	.163
460		16.23	5.364	2.179	1.019	.529	.177
480		17.59	5.815	2.363	1.104	.573	.192
500		19.01	6.284	2.554	1.193	.620	.208
550		22.79	7.532	3.060	1.430	.742	.249
600		26.88	8.886	3.611	1.687	.876	.294
650		31.30	10.35	4.204	1.965	1.020	.342
700		36.03	11.91	4.839	2.262	1.174	.394
750		41.08	13.58	5.517	2.520	1.339	.449
800			15.35	6.237	2.915	1.513	.507
850			17.22	6.999	3.271	1.698	.569
900			19.20	7.801	3.646	1.893	.635
950			21.28	8.645	4.041	2.097	.703
1000			23.45	9.530	4.454	2.312	.775
1100			28.11	11.42	5.338	2.771	.929
1200			31.75	13.58	6.298	3.269	1.096

See footnotes at end of table.

Table 4-9--Friction loss in feet per 100 feet in main lines of portable aluminum pipe with couplings--Continued

Flow (gallons per minute)	3-inch[2] (2.914)	4-inch[2] (3.906)	5-inch[2] (4.896)	6-inch[2] (5.884)	7-inch[2] (6.872)	8-inch[2] (7.856)	10-inch[2] (9.818)
1300				15.69	7.333	3.806	1.277
1400				18.06	8.441	4.382	1.470
1500				20.59	9.624	4.996	1.675
1600				23.28	10.88	5.648	1.894
1700				26.12	12.21	6.337	2.125
1800					13.61	7.064	2.369
1900					15.08	7.829	2.625
2000					16.62	8.630	2.894

[1] Where 20-ft. sections of pipe are used, increase values shown in the table by 7.0 percent.
Where 40-ft. sections of pipe are used, decrease values shown in the table by 3.0 percent.

[2] Outside diameter, inside diameter in parentheses.

TABLE 4-10

TABLE OF PRECIPITATION - INCHES PER HOUR

Spacing (feet)	Gallons per minute from each sprinkler														
	2	3	4	5	6	7	8	9	10	11	12	15	18	20	25
30x30	.21	.32	.43												
30x40	.16	.24	.32	.40	.48	.52	.64	.72							
30x50			.25	.32	.38	.44	.51	.57	.64	.70	.76				
30x60				.27	.32	.37	.43	.48	.53	.58	.64	.80			
40x40		.18	.24	.30	.36	.42	.48	.54							
40x50				.24	.29	.33	.38	.43	.48	.53	.58				
40x60				.20	.24	.28	.32	.36	.40	.44	.48	.60	.72	.80	
50x50					.23	.27	.31	.35							
50x60					.19	.22	.26	.29	.32	.35	.39	.48	.58	.64	
50x70						.19	.22	.25	.28	.30	.33	.41	.49	.55	.69
60x60							.21	.24	.27	.29	.32	.40	.48	.53	.67
60x70								.20	.23	.25	.27	.34	.41	.46	.57
60x80									.20	.22	.24	.30	.36	.40	.50

TABLE 4-11

GROSS IRRIGATION APPLICATION

Net Irrig. Depth (Inches)	Gross Irrigation Depth for Design Efficiency					
	80	75	70	65	60	55
1.6	2.00	2.13	2.28	2.46	2.67	2.91
1.8	2.25	2.40	2.57	2.77	3.00	3.27
2.0	2.50	2.66	2.86	3.08	3.33	3.64
2.2	2.75	2.93	3.14	3.39	3.67	4.00
2.4	3.00	3.20	3.43	3.70	4.00	4.37
2.6	3.25	3.46	3.71	4.01	4.33	4.73
2.8	3.50	3.73	4.00	4.32	4.67	5.09
3.0	3.75	4.00	4.28	4.63	5.00	5.45
3.2	4.00	4.26	4.57	4.93	5.33	5.82
3.4	4.25	4.53	4.86	5.24	5.67	6.18
3.6	4.50	4.79	5.14	5.55	6.00	6.55
3.8	4.75	5.06	5.43	5.86	6.33	6.91
4.0	5.00	5.33	5.71	6.17	6.67	7.28
4.2	5.25	5.60	6.00	6.47	7.00	7.64
4.4	5.50	5.86	6.28	6.78	7.33	8.00
4.6	5.75	6.12	6.57	7.09	7.67	8.36
4.8	6.00	6.39	6.86	7.40	8.00	8.73
5.0	6.25	6.65	7.14	7.71	8.33	9.10
5.2	6.50	6.92	7.43	8.02	8.67	9.46
5.4	6.75	7.18	7.71	8.33	9.00	9.82
5.6	7.00	7.45	8.00	8.63	9.33	10.18

TABLE 4-12

Days to Cover Given Distance

(Sheet 1 of 2)

Irr. Int. Days	Spacing of Laterals Along Main												Irr. Int. Days
	40	50	60	70	40	50	60	70	40	50	60	70	
	Distance Moved 1 Lateral 1 Move/Day				Distance Moved 1 Lateral 2 Moves/Day or 2 Laterals 1 Move/Day				Distance Moved 1 Lateral 3 Moves/Day or 3 Laterals 1 Move/Day				
5	200	250	300	350	400	500	600	700	600	750	900	1050	5
5½					440	550	660	770					5½
6	240	300	360	420	480	600	720	840	720	900	1080	1260	6
6½					520	650	780	910					6½
7	280	350	420	490	560	700	840	980	840	1050	1260	1470	7
7½					600	750	900	1050					7½
8	320	400	480	560	640	800	960	1120	960	1200	1440	1680	8
8½					680	850	1020	1190					8½
9	360	450	540	630	720	900	1080	1260	1080	1350	1620	1890	9
9½					760	950	1140	1330					9½
10	400	500	600	700	800	1000	1200	1400	1200	1500	1800	2100	10
10½					840	1050	1260	1470					10½
11	440	550	660	770	880	1100	1320	1540	1320	1650	1980	2310	11
11½					920	1150	1380	1610					11½
12	480	600	720	840	960	1200	1440	1680	1440	1800	2160	2520	12
12½					1000	1250	1500	1750					12½
13	520	650	780	910	1040	1300	1560	1820	1560	1950	2340	2730	13
13½					1080	1350	1620	1890					13½
14	560	700	840	980	1120	1400	1680	1960	1680	2100	2520	2940	14
14½					1160	1450	1740	2030					14½
15	600	750	900	1050	1200	1500	1800	2100	1800	2250	2700	3150	15
15½					1240	1550	1860	2170					15½
16	640	800	960	1120	1280	1600	1920	2240	1920	2400	2880	3360	16
16½					1320	1650	1980	2310					16½

TABLE 4-12 (cont'd)

Days to Cover Given Distance

(Sheet 2 of 2)

Irr. Int. Days	Spacing of Laterals Along Main												Irr. Int. Days
	40	50	60	70	40	50	60	70	40	50	60	70	
	2 Laterals---2 Moves/Day or 4 Laterals---1 Move/Day				5 Laterals---1 Move/Day				2 Laterals---3 Moves/Day or 3 Laterals---2 Moves/Day 6 Laterals---1 Move/Day				
5	800	1000	1200	1400	1000	1250	1500	1750	1200	1500	1800	2100	5
5½	880	1100	1320	1540					1320	1650	1980	2310	5½
6	960	1200	1440	1680	1200	1500	1800	2100	1440	1800	2160	2520	6
6½	1040	1300	1560	1820					1560	1950	2340	2790	6½
7	1120	1400	1680	1960	1400	1750	2100	2450	1680	2100	2520	2940	7
7½	1200	1500	1800	2100					1800	2250	2700	3150	7½
8	1280	1600	1920	2240	1600	2000	2400	2800	1920	2400	2880	3360	8
8½	1360	1700	2040	2380					2040	2550	3060	3570	8½
9	1440	1800	2160	2520	1800	2250	2700	3150	2160	2700	3240	3780	9
9½	1520	1900	2280	2660					2280	2850	3420	3990	9½
10	1600	2000	2400	2800	2000	2500	3000	3500	2400	3000	3600	4200	10
10½	1680	2100	2520	2940					2520	3150	3780	4410	10½
11	1760	2200	2640	3080	2200	2750	3300	3850	2640	3300	3960	4620	11
11½	1840	2300	2760	3220					2760	3450	4140	4830	11½
12	1920	2400	2880	3360	2400	3000	3600	4250	2880	3600	4320	5040	12
12½	2000	2500	3000	3500					3000	3750	4500	5250	12½
13	2080	2600	3120	3640	2600	3250	3900	4550	3120	3900	4680	5460	13
13½	2160	2700	3240	3780					3240	4050	4860	5670	13½
14	2240	2800	3360	3920	2800	3500	4200	4950	3360	4200	5040	5880	14
14½	2320	2900	3480	4060					3480	4350	5220	6090	14½
15	2400	3000	3600	4200	3000	3750	4500	5250	3600	4500	5400	6300	15
15½	2480	3100	3720	4340					3720	4650	5580	6510	15½
16	2560	3200	3840	4480	3200	4000	4800	5600	3840	4800	5760	6720	16
16½	2640	3300	3960	4620					3960	4950	5940	6930	16½

TABLE 4-13

Maximum Sprinklers Per Line for Given Spacings and Gallons Per Minute

G.P.M. Per Sprinkler	Sprinkler Spacing	2" OD Pipe			3" OD Pipe			4" OD Pipe			5" OD Pipe			6" OD Pipe		
		35	45	55 psi	35	45	55 psi	35	45	55 psi	35	45	55 psi	35	45	55 psi
2.0	20	27	30	33	56	60	65	90	100							
2.5	20	24	26	29	48	53	57	80	86	92						
	30	19	21	24	42	46	49	65	75	80						
3.0	20	20	23	25	42	47	50	70	76	82						
	30	18	20	22	38	41	44	60	66	72						
4.0	20	18	19	20	36	40	42	59	64	68	85					
	30	15	16	18	31	34	36	50	56	60	75					
5.0	20	15	16	18	31	34	36	50	56	60	75	81				
	30	14	14	15	27	29	32	44	48	52	65	70	75			
	40	12	12	14	24	26	28	40	44	47	59	64	69	78	85	90
6.0	20	13	14	15	28	30	32	46	50	53	66	73	78	90	96	103
	30	11	12	13	24	26	28	40	43	46	59	63	67	77	84	90
	40	10	11	12	21	23	25	36	39	42	52	57	60	70	76	81
7.0	20	12	13	14	25	27	29	42	45	48	60	65	70	80	86	93
	30	10	11	12	21	24	25	36	40	42	54	57	61	70	76	80
	40	9	10	11	19	21	23	32	35	38	48	52	55	63	69	74
8.0	20	11	12	13	23	25	27	38	41	44	56	60	64	74	80	85
	30	9	10	11	20	21	23	33	36	38	48	53	56	64	70	74
	40	8	9	10	17	19	20	30	32	34	44	48	50	58	63	67
10.0	20	9	10	11	20	21	23	32	36	38	48	52	56	64	70	75
	30	8	9	9	17	19	20	29	31	33	42	46	49	56	61	64
	40	7	8	8	15	16	18	26	28	30	38	41	44	50	53	59
12.5	20	8	9	9	17	18	19	28	30	33	42	45	49	56	60	64
	30	7	7	8	14	16	17	25	27	28	37	40	42	49	53	56
	40	6	6	7	13	14	15	22	24	26	31	36	39	43	47	51
15.0	30	6	6	7	13	14	15	22	24	25	32	35	38	43	47	50
	40	5	6	6	11	12	13	19	21	23	29	32	34	39	42	45
	50	5	5	6	10	11	12	18	19	21	27	29	31	36	40	42

Loss of pressure due to friction allowed - 20% of the Average sprinkler operating pressure. Other spacings, pressures and pipe sizes can be interpolated from the figures given.
For use with sprinkler lines with two or more sizes (60% of the difference between pipe sizes added to number of sprinklers for the smaller size pipe) THIS TABLE COURTESY OF BUCKNER SPRINKLER COMPANY

TABLE 4-13 (cont'd)

Maximum Sprinklers Per Line for Given Spacings and Gallons Per Minute

G.P.M. Per Sprinkler	Sprinkler Spacing	2" OD Pipe			3" OD Pipe			4" OD Pipe			5" OD Pipe			6" OD Pipe		
		35	45	55 psi	35	45	55 psi	35	45	55 psi	35	45	55 psi	35	45	55 psi
20.0	30	5	5	6	11	11	12	18	19	21	27	29	31	36	39	42
	40	4	4	5	9	10	11	16	17	19	24	26	28	32	35	38
	50	3	4	4	8	9	10	14	16	17	22	24	26	30	32	35
25.0	30	4	4	5	9	10	10	15	16	18	23	25	27	31	34	36
	40	3	4	4	8	9	9	14	15	16	20	22	24	28	30	32
	50	2	3	4	7	8	8	12	14	15	18	20	22	26	28	30
30.0	30	3	3	4	8	8	9	13	14	16	20	22	24	28	30	32
	40	2	3	3	7	8	8	12	13	14	18	20	21	24	27	29
	50	2	2	3	6	7	7	11	12	13	16	18	19	22	24	26
G.P.M. Per Sprinkler	Sprinkler Spacing	4" OD Pipe			5" OD Pipe			6" OD Pipe			7" OD Pipe			8" OD Pipe		
		60	80	100 psi	60	80	100 psi	60	80	100 psi	60	80	100 psi	60	80	100 psi
40.0	40	12	13	14	18	20	22	24	28	30	30	34	38	38	42	45
	60	10	11	12	16	17	18	21	24	26	26	29	32	32	36	39
	80	9	10	11	14	16	17	19	21	23	24	26	29	29	32	35
50.0	40	10	11	12	16	17	18	21	24	26	26	30	32	32	36	39
	60	9	10	11	13	14	16	18	20	22	23	25	28	28	31	33
	80	8	9	9	12	13	14	16	18	20	20	23	25	25	28	30
60.0	40	9	10	11	14	15	16	18	20	22	24	26	28	29	32	34
	60	8	9	9	12	13	14	16	18	19	20	22	24	25	28	30
	80	7	8	8	10	12	13	14	16	18	18	20	22	22	25	27
80.0	60	6	7	7	10	11	12	13	14	16	16	18	20	20	23	25
	80	6	6	7	9	10	10	12	13	14	14	16	18	18	20	22
	100	5	6	6	8	9	9	11	12	13	13	15	16	16	18	20
100	80	5	5	6	7	8	9	10	11	12	12	14	16	16	18	19
	100	5	5	5	7	7	8	9	10	11	11	13	14	14	16	18
	120	4	4	5	6	7	8	8	10	10	11	12	13	13	15	16

Loss of pressure due to friction allowed - 20% of the Average sprinkler operating pressure. Other spacings, pressures and pipe sizes can be interpolated from the figures given.

For use with sprinkler lines with two or more sizes (60% of the difference between pipe sizes added to number of sprinklers for the smaller size pipe) THIS TABLE COURTESY OF BUCKNER SPRINKLER COMPANY

TABLE 4-14

CONVERSION TABLES

Volume

1 gallon	=	231 cubic inches
1 gallon	=	0.1337 cubic feet
1 cubic foot	=	1,728 cubic inches
1 cubic foot	=	7.48 gallons
1 acre foot	=	43,560 cubic feet
1 acre foot	=	325,850 gallons
1 acre inch	=	27,154 gallons

Weight

1 gallon	=	8.34 pounds
1 cubic foot	=	62.4 pounds

Flow

1 gpm	=	0.00223 cfs
1 gpm	=	1,440 gallons per day (24 hrs.)
1 cfs	=	7.48 gallons per second
1 cfs	=	448.8 gpm
1 cfs	=	1.98 acre feet per day (24 hrs.)
1 $\frac{\text{acre inch}}{\text{hour}}$	=	452.5 gpm

(cfs = cubic feet per second)

(gpm = gallons per minute)

Pressure

1 foot of water = 62.4 pounds per square foot

1 foot of water = .433 pounds per square inch

1 pound of water per square inch = 2.31 feet of water

TABLE 4-15

WATER PRESSURE TABLE

Pounds Per Square Inch and Head Feet Equivalents

Head (Feet)	Lbs. Per Sq. In.	Head (Feet)	Lbs. Per Sq. In.	Head (Feet)	Lbs. Per Sq. In.
1	.43	30	12.99	140	60.63
2	.87	40	17.32	150	64.96
3	1.30	50	21.65	160	69.29
4	1.73	60	25.99	170	73.63
5	2.17	70	30.32	180	77.96
6	2.60	80	34.65	190	82.29
7	3.03	90	38.98	200	86.62
8	3.46	100	43.31	250	108.27
9	3.90	110	47.64	300	129.93
10	4.33	120	51.97	400	173.24
20	8.66	130	56.30	500	216.55

Formula Used In Design and Evaluation Examples

a. Precipitation Rate From Center Pivot Systems

$$I = \frac{96.3\ Q_s}{D\ \ S_B}$$

Where: I = Precipitation or application rate in inches per hour
D = Wetted diameter of sprinkler nozzle in feet
S_B= Spacing of nozzles along the boom in feet
Qs= Discharge from individual sprinkler in GPM

b. Gross Application Depth in Inches from Individual Sprinklers on a Center Pivot.

$$d = \frac{Q_s}{0.62\ S_B\ \ V}$$

Where: d = Application Depth in inches (gross)
V = Velocity or rotational speed of individual sprinkler along the boom in feet/minute.

c. Equations a and b can be combined to relate terms into a relationship sometimes useful.

$$V = \frac{D\ I}{60\ d}$$

d. Total Capacity Requirements based on known application depth, area, and time of application.

$$Q = \frac{453\ Ad}{FH}$$ (Refer to Figure 4-8 and Figure 4-9)

Where: Q = Total system discharge capacity in GPM
A = Acreage of the design area to be sprinkler irrigated in acres.
d = gross depth of application in inches
F = Number of days allowed for completion of one irrigation
H = Number of actual operating hours per day

Example Problem: Center Pivot System Design - Adequate Water Supply

Given:
a. Center pivot without end gun
b. Crop - Potatoes
c. Acreage - 160 Acre Field
d. Soil - Estherville
e. Location - Pope County, Minnesota (Climatic Area 2)
f. Slope - Between 2 and 5 percent.
g. Ground cover - Assume plant foliage is not adequate ground cover. Assume residue between 1,000# and 2,000#.

Step 1 - Determine Irrigation Depth
2.0 Feet (See Table 2-8, page 2-25)

Step 2 - Determine Available Water Holding Capacity
Chapter 3 - Irrigation Group 8, 2.6 Inches (At 20 inches)

Step 3 - Determine Net Application at 50 Percent Depletion
2.6 Inches x 50 percent = 1.3 Inches (Net)

Step 4 - Determine Maximum Allowable Application Rate
Irrigation Group 8 is in Intake Family 1.5
See Table 3-4 on page 3-5.
Basic Rate = 1.60 Inches per hour
Adjust for row crop with 1,000 - 2,000# of residue.
Adjusted Rate = 1.60 Inches/hour x 0.70 = 1.12 Inches/hour

Step 5 - Determine Irrigation Frequency During the Peak Use Period

$$\text{Irrigation Frequency} = \frac{\text{Net Irrigation Application}}{\text{Peak Period Daily Use Rate}}$$

See Table 2-7 on page 2-24 for Peak Daily Use Rate for Climatic Area 2, Potatoes and 1.3 Inch application;
Peak Use Rate = 0.27 inches/day

$$\text{Irrigation Frequency} = \frac{1.3 \text{ Inches}}{0.27 \text{ Inches/day}} = 5 \text{ days}$$

This sets the slowest rate of revolution for the system.

Step 6 - Determine Rate of Travel at the Outermost Drive Wheel (Generally located about 50 feet from the end of the boom).
System length = 1,300 feet total
Distance to Drive Wheel = 1,300 - 50 = 1,250 feet
Length of last drive wheels path in one revolution = $2\pi r = 2(3.14)\ (1{,}250) = 7{,}850$ feet

$$\text{Velocity} = \frac{7{,}850 \text{ feet}}{5 \text{ days x } 24 \text{ hours/day x } 60 \text{ min/hour}} = 1.10 \text{ ft/min.}$$

Note: The time of rotation could be less than 5 days but would require greater total capacity in GPM and higher application rates.

Step 7 - Determine Sprinkler Application Rate Required to Apply The Required Net Application of 1.3 Inches.

$$\text{Gross Application} = \frac{\text{Net Application (See Step 3)}}{\text{Efficiency (See Table 4-5)}}$$

$$= \frac{1.3 \text{ In.}}{0.75} = \underline{1.73 \text{ Inches}}$$

Individual Sprinkler Application Rate is given by equation;
$Qs = 0.62\ S_B\ d\ V$

Where Q_s = Sprinkler Discharge in GPM
S_B = Sprinkler Spacing on the Boom in Feet
d = Gross Application Depth in Inches
V = Rate of Travel in Feet/minute

Assume S_B = 30 feet

$Qs = 0.62\ (30)\ (1.73)\ (1.10)$
$Q_s = 35.4$ GPM

Step 8 - Determine Minimum Wetted Diameter for Sprinkler by Equation:

$$D = \frac{96.3\ Q_s}{I\ S_B}$$

Where D = Wetted Diameter in Feet
Q_s = Sprinkler Discharge in GPM
I = Maximum Allowable Application Rate, In/hr
S_B = Spacing, feet

$$D = \frac{96.3\ (35.4)}{1.12\ (30)}$$

D = 101 feet.--this is the minimum wetted diameter that can be selected for a nozzle to apply 35.4 GPM without exceeding the allowable application rate.

Step 9 - Select a Nozzle Size for Use Along Last 100 Feet of Boom. See Table 4-3 on page 4-23.
Operating pressure at this point on the boom should be about 60 psi. Therefore, the pressure is known, the minimum wetted diameter, and the required discharge are known. From Table 4-3 select the nozzle size of 13/32" @ 60 psi produces 35.9 GPM with a wetted diameter of 165 feet.

Step 10 - Check Actual Depth of Application and Rate of Application for This Nozzle.

Find Rate: $I = \frac{96.3\ Q_s}{D\ \ S_B}$

I = 0.70 inches/hour: This is the average rate applied to a point on the ground surface as the moving lateral passes overhead. A sprinkler produces a parabolic distribution with the maximum rate directly under the sprinkler. The maximum rate is 1.5 times the average (0.70 x 1.5 = 1.05 in/hr). This is less than 1.12 and is satisfactory.

Actual Depth Applied

Check this by multiplying the application rate by the time that it takes for the wetted diameter to be traversed. Given by equation $Q_s = 0.62\ S_B\ d\ V$

Solve for $d = \frac{Q_s}{.62\ S_B\ V} = \frac{35.9}{.62\ (30)\ (1.10)} = 1.75$ Inches

OK, Step 7 shows gross amount of 1.73 Inches.

Another way of checking is using the equation shown on the following page.

$$I = \frac{60 \quad d\ V}{D}$$

$$d = \frac{I\ D}{60\ V}$$

$$d = \frac{0.70\ (165)}{60\ (1.10)}$$

$$d = 1.75 \text{ Inches}$$

This is simply determining the time to traverse the wetted diameter. $\left(\frac{165 \text{ feet}}{1.10 \text{ ft/min.}} = 150 \text{ minutes.}\right)$
Which equals 2.50 hours$\left(\frac{150}{60}\right)$. The application rate is 0.70 inches/hour (average) x 2.50 Hours = 1.75 Inches.

Step 11 - Determine Total Irrigation System Capacity.
In order to get equal application of water, the last 100 feet of the circular distribution must receive 14.8% of the total water. For a 1,300 foot long boom this 100 feet covers 14.8% of the total area of the circle (See Table 4-1). Therefore, total capacity is determined as follows:

Q_s = 35.9 GPM at a 30 foot spacing - $\frac{35.9 \text{ GPM}}{30 \text{ feet}}$ = 1.197 GPM/Ft.

Last 100 feet will use 1.197 $\frac{\text{GPM}}{\text{Ft.}}$ x 100 feet = 119.7 GPM

Qt x 14.8% = 119.7 GPM

$$Qt = \frac{119.7}{.148}$$

$$Qt = 810 \text{ GPM}$$

An alternate procedure is to use figure 4-9 on page 4-19. From Step 10, the depth (gross) of application is 1.73 inches. The maximum irrigation period is the same as the irrigation frequency from Step 5.

$d/F = \frac{1.73}{5.0} = 0.35$ and the system length is a $\frac{1}{4}$ section at 1,320 feet. Figure 4-9 shows Q_t = 820 GPM
If an end gun is desired then its discharge must be added directly to the 810 GPM.

Step 12 - Check Erosion Hazard of the Operation.
(a) Determine soil loss by water for continuous potatoe crops. Refer to Section III-A, Technical Guide, "Estimating Soil Loss Resulting from Water and Wind Erosion in the Midwest."
R = 100 (Climatic Area 2)
K = 0.17 for Estherville sandy loam (new "K" tables)
T = 3.0 Tons/Acre/Year
LS = 0.40 for average field conditions of 3.0 percent slopes and 150 feet slope length.

C = 0.40 for continuous potatoes from Section III of Table 2A use value for continuous corn and adjust upward for potatoes.

P = 1.0

Therefore A = 2.7 Tons/Ac/Year

This is an acceptable level of treatment. When potatoes are continuous, 1500 pounds per acre of potatoe residue should remain on the surface at planting time. Otherwise, alternative measures would need to be developed using Table 2A Section III of the Technical Guide to maintain a "C" factor of 0.4 or less.

(b) Determine wind erosion loss from Section III-A of the Technical Guide.

Allowable soil loss = 3.0 Tons/Acre/Year

I = Soil Erodibility (86)
K = 0.75 (semi-ridged)
C = 10
L = 5,000 ft. (2,640 x 1.86 from Table 6)
V = 1,500 lb. of potatoe vine residue. Use peanuts curve from Chart 3 as potatoes. The equivalent amount of flat small grain is 300 lb/acre.
E = 4.6 Tons/Acre/Year which exceeds the allowable value of 3.0 Tons/Acre/Year

Therefore, the unsheltered distance may be reduced by installing barriers or increase the amount of residue on the surface. If crop damage is being considered, the allowable soil loss is found in Table 1b of Section III-A.

The next example illustrates how management changes can be made to use a limited water supply. Briefly, there are three things to consider in planning to utilize a limited water supply.

1) Water capacity demands will decrease as sprinkler operation approaches 24 hours per day.
2) Allow only a 20% or 30% depletion below field capacity instead of 40% or 50% as is commonly used. This decreases the application depth. For instance, if the AWC is 4.0 inches, then the normal 50% application is 2.0 inches. Using 25% depletion, the application depth becomes 1.0 inches.
3) A peak consumptive use rate can be based upon an average of a longer period, i.e. 0.24 in/day might be all right versus 0.27 in/day especially if the root zone is managed at 75% AWC.

<u>Example Problem 2</u>: Center Pivot System Design - Limited Water Supply

Given:
a. Center Pivot Without End Gun
b. Water Supply is 400 GPM
c. Crop - Potatoes
d. Acreage - 160 Acres

e. Soil - Estherville
f. Location - Pope County, Minnesota (Climatic Area 2)
g. Slope - Between 2 and 5 percent.
h. Ground cover - 1000# - 2000# of residue.

To best utilize an available but limited water supply with a center pivot system, adjustments can be made in the area irrigated, the depth of application, and the speed of rotation.

There are two basic conditions to meet in selecting a combination of these three variables. One, is the capacity limitation based upon the percent of the water supply that has to be applied in the last 100 feet of the system for uniform application. The other condition is the area covered and crop limitations in terms of system length and time of rotation.

Step 1 - Crop limitations are based upon a use rate of 0.27 inches/day and the net depth of application. The minimum rotation speed is dependent upon the net application divided by maximum consumptive use rate.

$$\text{Irrigation Frequency} = \frac{d\ (\text{net})}{0.27\ \text{inches/day}}$$

$$d\ (\text{gross}) = \frac{1.0}{0.75} = 1.33\ \text{inches}$$

Step 2 - Compute Q_S based upon a 1000 foot system

19.0% of 400 GPM will be required in last 100 feet.

$$Q_S = 400\ (.19) = 76\ \frac{\text{GPM}}{100\ \text{Ft.}} \times 30\ \text{feet.}$$

$$Q_S = 22.8\ \text{GPM}$$

Step 3 - Compute velocity of last drive wheel at 50 feet from end.

$$V = \frac{2\pi(950)}{3.7\ \text{days} \times 24 \times 60} = 1.12\ \text{feet/minute}$$

Step 4 - Check Q_S by equation dependent of d, V, and spacing.

$$Q_S = 0.62\ S_B\ d\ V$$

$$Q_S = 0.62\ (30)\ (1.33)\ (1.12)$$

$$Q_S = 27.7\ \text{GPM - Too High } 27.7 > 22.8$$

Step 5 - Try a 900 Foot System
Q_S (from Table 4-1 on page 4-21) will require 21% of water application in the last 100 feet.

$$Q_S = 0.21\ (400) = 84\ \text{GPM/100 feet} \times 30\ \text{Feet}$$

$$Q_S = 25.2\ \text{GPM}$$

Step 6 - Compute rotation speed of last drive wheel.

$$V = \frac{2\pi(850)}{3.7 \times 24 \times 60} = 1.0\ \text{foot/minute}$$

Step 7 - Check Q_S by equation relating d, V, and spacing.

$$Q_S = 0.62\ S_B\ D\ V = 0.62\ (30)\ (1.33)\ (1.0)$$

$$Q_S = 24.7\ \text{GPM - Ok slightly less than Step 5.}$$

Step 8 - Compute rate of application and compare to allowable rate from Table 3-4 and Step 4 of example problem 1.

$$I = \frac{96.3\ Q}{D\ \ S_B}$$ (From Table 4-3 select 3/8" nozzle at pressure of 40-45 psi and D = 145 ft.)

$$I = \frac{96.3\ (24.7}{145\ (30)}$$

I = 0.55 Inches/Hour - Ok 1.12 Inches/Hour

Step 9 - Check actual application depth by computing the time elapsed to traverse the wetted diameter.

$$\text{Time} = D/V = \frac{145 \text{ feet}}{1.0 \text{ feet/minute}}$$

Time = 145 minutes = 2.417 Hours

d actual = 0.55 Inches/hour x 2.417 hours = 1.33 Inches - Ok

An alternate procedure for determining maximum area that can be adequately irrigated with a limited water supply is to use Figure 4-9 and applying a minimum application of 1.33 inches (gross application). Available water supply is 400 GPM and minimum irrigation time is 1.0/0.27 - 3.7 days operating 24 hours per day. Figure 4-9 shows that about 66 acres is the maximum that can be irrigated with the given water supply. The 900 feet center pivot selected covers approximately 60 acres.

Example Problem 2A

Given: Same as Problem 2. Plan for two systems with 200 GPM each.
Solution: Break field into 4 - 40 acre fields. Use system length of 650 feet. Use minimum application of 1.0 inch (net). Gross application = 1.33 inches. Make a trial using two 650 foot systems at 200 GPM each.

Step 1 - Determine maximum rotation time or minimum rotational velocity. $\frac{1.0 \text{ inches}}{0.27 \text{ inches/hour}} = 3.7$ days; $\frac{d}{F} = \frac{1.33}{3.7} = 0.36$

Figure 4-9 shows that 200 GPM is adequate for a 650 foot system.

Step 2 - Compute water required in last 100 feet.

Q_{100} = 28.4% of Q_t (Table 4-1)

Q_{100} = .284 (200)

Q_{100} = 56.8 GPM per last 100 feet

$$Q_s = \frac{56.8}{100} \times 30$$

Q_s = 17.04 GPM

Step 3 - Check application rate from selected nozzle discharge, 30 foot spacing and wetted diameter.

From Table 4-3 select 9/32" nozzle at 60 psi to produce 17.7 GPM; the wetted diameter is 125 feet @ 60 psi.

$$I = \frac{96.3\ Q_s}{D\ \ S_B}$$

$$I = \frac{96.3\ (17.7)}{(30)\ \ (125)}$$

$$I = 0.45 \text{ in/hr} \quad \text{Ok.}$$

Step 4 - Compute minimum rotational speed at the last tower required to complete one revolution in 3.7 days.

$$V = \frac{6.20\ (600)}{3.7 \text{ days}} = \frac{3{,}768 \text{ feet}}{3.7 \text{ days}}$$

$$V = 1{,}018 \text{ ft/day} = 0.71 \text{ ft/min}$$

Step 5 - Check actual application depth.

$$d = \frac{Q_s}{0.625_B\ V} = \frac{17.7}{(0.62)\ (30)\ (0.71)}$$

$$d = 1.34 \text{ inches - Ok}$$

Another alternative is to install one 650 ft. system to operate on 400 GPM and design it so that two 40 acre fields can be covered by a move within the 3.7 day irrigation frequency. This is illustrated in Steps 6 through 12.

Step 6 - Go to one system at 400 GPM. Operator must utilize the best management techniques to limit damage caused by moisture deficiency with this design because of the short irrigation frequency involved with light applications.

Step 7 - Compute water required in last 100 feet.

$$Q_{100} = .234\ (400)$$

$$Q_{100} = 113.6 \text{ GPM/100 feet}$$

$$Q_s = 113.6 \times \frac{30}{100}$$

$$Q_s = 34.1 \text{ GPM}$$

Step 8 - Check application rate from 34.1 GPM with 30 foot spacing and wetted diameter for 34.1 GPM 2 about 60 psi. From Table 4-3 on page 4-23 a 13/32 inch nozzle produces 35.9 GPM at 60 psi with Dw = 165 feet.

$$I = \frac{96.3\ Q_s}{D\ S_B} = \frac{96.3\ (35.9)}{(165)\ (30)}$$

$$I = 0.70 \text{ inches/hour (ok)}$$

$$\text{Maximum } I = 1.5 \times 0.7$$

$$\text{Maximum } I = 1.05 \text{ inches/hour} < 1.12 \quad \text{ok}$$

Step 9 - Check to see if smaller wetted diameter can be used. At 55 psi use 13/32 nozzle @ 34.3 GPM (D = 145)

$$I = \frac{96.3\ (34.3)}{145\ (30)} = 0.76 \text{ inches/hour} \therefore \text{ ok}$$

Step 10 - Compute maximum rotation speed at center of the last 100 ft. section.

$$V = Q_s/.62\ S_B\ d = \frac{34.3}{.62\ (30)\ (1.33)}$$

$$V = 1.39 \text{ feet/minute}$$

Step 11 - Compute actual rotation interval. Master tower is at 600 ft.

$$t = \frac{L}{V} = \frac{6.28\ (600)}{1.39}$$

$$t = 2{,}711 \text{ minutes} = 45.2 \text{ hours}$$

$$t = 1.88 \text{ days.} < 3.7 \text{ days ok}$$

Step 12 - Check Actual Application Depth
Time to traverse one wetted diameter is:

$$\frac{145 \text{ ft.}}{1.39 \text{ ft/min.}} = 104.3 \text{ minutes} = 1.74$$

I (Actual) = 0.76 inches/hour x 1.74 hours = 1.32 inches ok

Example Problem: Traveling Gun

Given:
a. Continuous Move Volume Gun
b. Crop - Potatoes
c. 80 Acre Field
d. Soil - Becker
e. Location (Climatic Area 2)
f. Slope - Less than 2%
g. Cover - Use 1000# - 2000# residue.

Step 1- Determine Irrigation Depth
Table 2-8 on page 2-25 shows 2.0 feet.

Step 2- Determine the AWC
Becker soil is in Irrigation Group 6 in Chapter 3
The AWC = 3.96 inches

Step 3- Determine the maximum allowable application rate.
Irrigation Group 6 is in Intake Family 1.5 - Use Table 3-4 on page 3-5.
Basic rate = 2.0 inches/hour
Residue Adjustment = 0.70 x 2.0 = 1.4 inches/hour
Maximum Application Rate = 1.4 inches/hour

Step 4- Determine Net and Gross application depths at 48% depletion.

3.96 inches x 0.48 = 1.9 inches (net)

1.9 ÷ 0.75 = 2.53 inches (gross)

Step 5- Compute the Irrigation Frequency (Maximum irrigation period)

$$\text{Irrigation Frequency} = \frac{1.9 \text{ inch}}{0.27 \text{ inches/day}} = 7.04 \text{ days}$$

Step 6 - Determine System Capacity the operator desires to operate the equipment 24 hours per day. Assume two hours per day will be used to effect the moving of equipment. Use Figure 4-8 on page 4-18 or the following equation:

$$Q = \frac{453\ A\ d}{F\ h}$$

$$Q = \frac{453\ (80)\ (2.53)}{7\ (22)}$$

Q = 595 gpm, therefore, use 600 gpm

Step 7 - Determine lane spacing, sprinkler size, and flexible hose capacity.

(a) Hose size for 600 gpm and 80 acres should be 4.5 inch diameter and 660 feet long. See attached table:

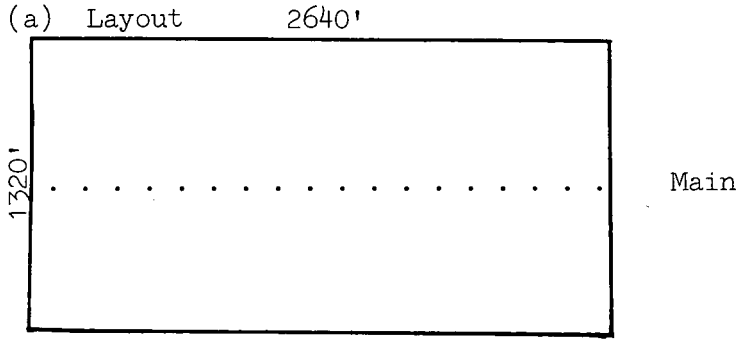
Area Covered (Acres)	System Capacity (gpm)	Recommended Hose Diameter (inches)	Standard Length (feet)
0 - 20	0 - 150	2.5	330,500 or 660
20 - 40	150 - 300	3	660
40 - 100	250 - 600	4	660
60 - 120	400 - 750	4.5	660
80 - 160	500 - 1000	5	660

(b) Lane Spacing - direction of travel should be at right angle to the prevailing wind if possible. Lane spacing is based upon wetted diameter and wind velocity. The maximum spacing ranges from 50% of the wetted diameter for wind over 10 mph to 80% with still conditions.

A Nelson 1.6" 200 series Big Gun discharges 630 gpm at 70 psi with a wetted diameter of 465 feet. Lane spacing will be 0.65 x 465 = 302 ft.

Step 8 - Determine system layout and performance requirements.

(a) Layout



$$\text{Number of Lanes} = \frac{\text{Length of field}}{\text{Lane Spacing}} = \frac{2640}{302} = 8.74$$

<u>Try 8 Lanes</u>

$$\text{Lane Spacing} = \frac{2640}{8} = 330 \text{ ft. spacing}$$

This provides $\frac{330}{465} = 71\%$ of Wetted Diameter. ok

8 Lanes ok

(b) Performance characteristics.

A continuous moving sprinkler started at a point one-half the wetted diameter in from the field edge will not have sufficient time to apply the design depth at the field edges. It is necessary to allow the gun to remain stationary at the beginning and end of each pass until one half the gross depth is applied. The time to complete one pass across the field is determined by subtracting one-half the wetted diameter from each side of the field.

$$\text{Stationary time} = \frac{d/2}{I} \text{ (at start)} + \frac{d/2}{I} \text{ (at end)}$$

$$= \frac{d}{I} \text{ in hours per pass}$$

$$\text{Moving time} = \frac{1320 - \text{wetted diameter}}{V}$$

The application rate from the selected gun is:

$$I = \frac{96.3\ Q}{\text{Area Covered by Wetted Diameter}}$$

$$I = \frac{96.3\ (630)}{\pi\ (465)^2/4} = 0.36 \text{ in/hr (average)}$$

$$I_{(max)} = 0.36 \times 1.5 = 0.54 \text{ in/hr (ok)}$$

$$\text{Stationary time} = d/I = \frac{2.53}{0.36} = 7.03 \text{ hours}$$

$$\text{Moving time} = \frac{1320 - 465}{\frac{(465)(.36)}{60(253)}} = 775 \text{ min.} = 12.9 \text{ hours}$$

$$\text{Total time for one pass} = 7.03 + 12.9$$

$$= 19.93 \text{ Hours}$$

$$8 \text{ passes} \times 19.93 \text{ Hrs/Pass} = 159 \text{ Hours}$$

$$= 6.64 \text{ Days}$$

This is less than 7.0 days but does not allow much slack time to make repairs or other down time.

Design Considerations For A Sprinkler System Using Lateral Lines Operating In Sets

Sprinkler systems operating in sets require the moving of the laterals at specific intervals of time. In order to fit in with farm schedules, it is generally recommended that the time of sets be planned for 7-, 11-, or 23-hour periods of time which allows one hour per set for moving the lines and servicing the equipment.

The following criteria used in conjunction with tables in this chapter provide data needed to make recommendations for the use of solid set systems.

1. The allowable variation in lateral line pressure should not exceed ± 10 percent of the design pressure.
2. For selection of most economical size, the loss in the main line should be 20 to 30 percent of the pressure at the pump.
3. 1.0 psi pressure - 2.31 feet of head.
4. 100 GPM applies .223 acre inches per hour.
5. Alternate lines should be staggered to give best application distribution and should not be spaced more than approximately 0.6 times wetted diameter of nozzles used.

The following example is not intended to show the complete design procedure but use only as a guide in general determination of suitability of a specific system and approximate size requirements to guide the user in equipment selection. For more specific design criteria, refer to Chapter 11 of Section 15 of the National Engineering Handbook, Sprinkler Irrigation.

Sprinkler Irrigation Using Laterals Operating in Sets

Problem:

Select sprinkler system to meet specific design requirements.

Given:

40-acre field with dimensions of 1320' x 1320' located in Climatic Area 5.
Soil: Renshaw loam
Crop: Soybeans

Well located at northeast corner of field. Well, pump and motor will be designed to supply the required capacity at 60 psi pressure at pump. Operator wants 11-hour settings (one setting per day). Prefers 40' x 60' spacing.

Solution:

(a) Determine maximum allowable application rate and design application depth. Renshaw loam is in Irrigation Group 11. The maximum irrigation depth for soybeans is 2.0 feet (from Table 2-8 on page 2-25). The total AWC at that depth is 3.96 inches (Irrigation Group 11). Irrigation starts at 50 percent depletion. Therefore, a net application of 1.90 inches will be used for design of the system. Renshaw loam falls under Intake Family

1.0. Slopes are between 2 and 5 percent. Therefore, the maximum application rate will be 1.0 inches/hour. (Table 3-4 on page 3-5).

(b) Determine sprinkler application efficiency. From Table 4-5 on page 4-25, find 65 percent efficiency for under 2 inches net application and an application rate over 0.5 inches/hour. Therefore, the gross application is 1.9/0.65 = 2.92

(c) Determine the design irrigation frequency or the maximum irrigation period.

$$\text{Irrigation Frequency} = \frac{\text{Net Application}}{\text{Peak daily use rate}}$$

$$= \frac{1.90 \text{ inches (from step "a")}}{0.28 \text{ inches/day (from Table 2-7)}}$$

$$= 6.8 \text{ days. Use 7 days.}$$

(d) Determine capacity requirements of the system.

$$Q = \frac{453\ A\ d}{F\ H}$$

$$Q = \frac{453\ (40)\ (2.93)}{7\ \ (11)}$$

$$Q = 690 \text{ GPM}$$

A = Area, in acres

d = gross depth of application, inches

F = Number of days allowed for completion of one irrigation.

H = Operating hours per day

(e) Determine the application rate needed to apply the gross application depth.

$$\frac{2.93 \text{ inches}}{11 \text{ hours}} = 0.27 \text{ inches/hour}$$

Table 4-6 on page 4-25 can also be used for this determination.

(f) Determine number of laterals based on 11 hour set and 690 GPM system capacity. Table 4-10 on page 4-30, shows that just about any combination of spacings can be selected between 0.27 inches/hour and 1.0 inches/hour. Select a spacing (Table 4-10) that provides something in excess of 0.27 inches/hour. Refer to Table 4-13 on page 4-34. Try a 40' x 60' - at 7 GPM/sprinkler

$$\text{Number of sprinklers/set} = \frac{690 \text{ GPM}}{7 \text{ GPM/sprinkler}} = 98.6 \text{ sprinklers at}$$

$$40' \text{ spacing; } \frac{1320 \text{ feet}}{40 \text{ feet}} = 33 \text{ sprinklers/laterals}$$

$$\frac{98.6}{33} = \text{laterals}$$

(g) Select sprinkler head from Table 4-4 on page 4-24. Assume that the main will have a 25 percent head loss across the field.

Then the pressure at the (0.75 x 60 = 45 psi) distal lateral and 60 psi at the lateral adjacent to the pump. The average pressure at the entrance to laterals would be (60 + 45) ÷ 2 = 52.5 psi.

From Table 4-4 on page 4-24 the RB 30W 3/16", RB 40 BW 3/16", or the RB 14070W 3/16" will provide (interpolation required between 45 and 50 psi on the table) 7.0 GPM. The wetted diameters are 99, 103, and 107 respectively.

The lateral spacing should not be more than about 0.6 of the wetted diameter. Spacing of laterals is 60 feet, therefore, minimum wetted diameter is $\frac{60}{0.6}$ = 100 feet.

Select the 3/16" RB30W.

(h) Determine lateral size. The allowable pressure variation in the sprinkler line is 10 percent of the design pressure or a range of ± 10 percent from 47 psi. This range is 42 psi to 52 psi. The allowable pressure drop is 10 psi which is equal to 23 feet of head.

Lateral Length = 1320 feet
Nozzles/lateral = 33
Allowable head loss = 23 feet
"F" factor = 0.36 (Table 4-8)
Flow in lateral= 7 GPM/sprinkler x 33 sprinklers = 231
Allowable loss/100 feet = $\frac{23}{13.2}$ ÷ 0.36 = 4.8 feet/100 feet

Refer to Table 4-7 on page 4-26 to find 231 GPM. A 4 inch lateral will have a head loss of 3.6 feet/100 feet. Total loss will be (3.6 x 13.2 x 0.36 = 17.1 ft.) therefore, 17.1 < 23. 4 inch aluminum - 30 foot lengths is satisfactory.

(i) Determine size of main line. Allowable head loss is about 25 percent of pump pressure.

H_f = 60 psi x .25 = 15 psi = 34.65 feet (Divide by 13.2 hundred ft.)

H_f = 2.66 feet/100 feet

From Table 4-9 on page 4-28 select 7 inches for 690 GPM.

With three laterals it may be possible, by adjusting the operation, to reduce the diameter of the last few hundred feet of the main.

Sprinkler System Evaluations

Systems operating in sets:

1. Loss in mainline should not exceed 30 percent of pump pressure.
2. Pressure in lateral should not vary more than plus or minus 10 percent from average pressure. This will assure a minimum application rate of at least 90 percent of maximum rate.
3. Spacing of nozzles along lateral should not be more than 50 percent of the wetted diameter. Spacing of laterals should not exceed 60 percent of wetted diameter.
4. The following rule-of-thumb may be used. The average sprinkler discharge can be computed as the discharge at the first nozzle less three-fourths the difference between the first and last nozzle.
5. When the time of set is near completion, the water applied by a nozzle should disappear from the surface by the time the nozzle makes a complete revolution.

PROCEDURE:

Determine the following:

1. The estimated net irrigation that is needed
2. Spacing of sprinklers and laterals
3. Size of sprinkler nozzles
4. Size of main and lateral lines
5. Size of field and predominant slope
6. Pressure at pump
7. Pressure at first and last nozzle
8. Pressure at and location of high point of line, if of appreciable significance.
9. Maximum length of main and lateral lines
10. Location of line in relation to field boundaries
11. Diameter of spray pattern
12. If application rate is exceeding soil intake rate

EXAMPLE:

1. Soil: Waukegan with predominant 2 percent slope Intake Family 0.5.
2. Crop: Alfalfa.
3. Net moisture needed: 3.0" (estimated by field check).
4. Spacing of sprinklers and laterals: (40' x 60') (Field observation).
5. Sprinkler nozzles:
   a. Size: 13/64 x 5/32 (checked in field)
   b. Number per line: 33
6. Diameter of spray pattern at last nozzle: 100 ft. (field observation).
7. Size of main and lateral lines: 7" x 4" (field observation)

8. Pressure at pump: 60# (read from pressure gauge).
9. Pressure at first nozzle: 45# (measured with pitot tube). Pressure at high point 580' or 15 nozzles from main. 30# (measured with pitot tube). Pressure at last nozzle 1,300' or 33 nozzles from end - 28# (measured as above).
10. Maximum lengths: Main line 1,290', lateral lines 1,300' each. (Two laterals with main in center.) Check made at 990' from pump (field check).
11. No water remains on surface by time nozzle makes a complete revolution.

SOLUTION:

1. Discharge from first nozzle at 45# pressure is 8.1 + 4.7 = 12.8 gpm (Table 4-3, on page 4-23).
2. Discharge at high point at 30# pressure is 6.5 + 3.9 = 10.4 gpm (Table 4-3, on page 4-23).
3. Discharge at last nozzle at 28# pressure is 6.3 + 3.7 = 10.0 (Table 4-3, on page 4-23).
4. Average discharge to high point = 12.8 - 3/4 (12.8 - 10.4) or 12.8-3/4(2.4) = 11.0 gpm (page 4-52, item 4). Average discharge, high point to end = 10.4 - 3.4(10.4-10.0) = 10.4-3/4(0.4) = 10.1 gpm. Average sprinkler line discharge $= \frac{15(11.0) + 18(10.1)}{33} = 10.5$ gpm. (See previous page, Item 9)
5. Pressure variance is 45 - 28 or 17#. The average pressure is

$$\frac{45 + 28}{2} \text{ or } 36.5\#.$$

The pressure varies 8.5# each way from the average or a pressure variance of

$$\frac{8.5}{36.5} = 23 \text{ percent from average.}$$

(Pressure variance should not exceed ± 10 percent; therefore, lateral lines are too small, item 2, page 4-52)

6. Loss in 7" main line = 15# for 990' length. For 1,290' to last lateral connection, the equivalent loss would be

$$\frac{1,290}{990} \times 15 = 19.5\#.$$

Maximum main line loss should be approximately 30 percent of pump pressure (page 4-52, item 1). 30% of 60# = 18.0#; therefore, main line is slightly small for optimum design but this loss is only at maximum distance and would not justify purchasing larger pipe.

7. Spray pattern diameter - 100' (observed, page 4-52, item 6). Lateral spacing should not exceed 60 percent of spray pattern or more than 60 feet. Therefore, lateral line spacing is satisfactory for 40' x 60' spacing.
8. Maximum application rate of 12.8 gpm on 40' x 60' spacing is approximately 0.5"/hr. (Table 4-10) Maximum allowable rate on alfalfa for 2.0% slope and 3" application is 0.65"/hr. (Table 3-4, page 3-5)

9. Minimum application rate is 10.0 gpm (last nozzle). Maximum rate is 12.8 gpm (first nozzle). Minimum rate is, therefore,

$$\frac{10.0}{12.8} \text{ or } 78\% \text{ of maximum.}$$

Minimum rate should be at least 90 percent of maximum (page 4-52, item 2). Therefore, pressure loss in lateral lines is excessive.

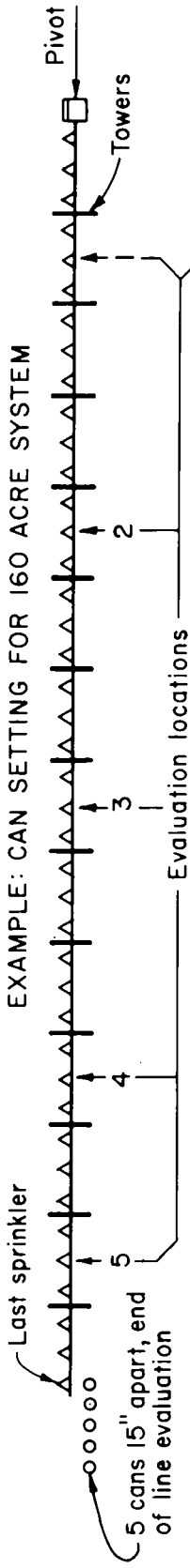
10. Design efficiency is 70 percent. (Table 4-5, page 4-25).
11. Minimum application rate of 10.0 gpm on 40' x 60' spacing is 0.4"/hr. (Table 4-10, page 4-30). To apply 3" at 70% efficiency would require

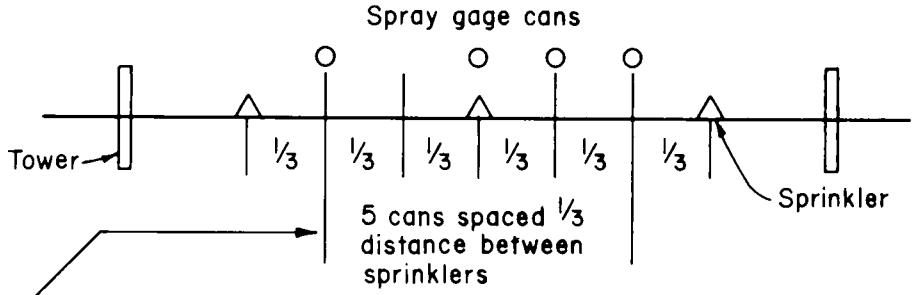
$$\frac{3.0}{.4 \times .70} = 10.7 \text{ hrs.}$$

12. No water remains on surface so application rate is satisfactory in regard to soil intake rate.

RECOMMENDATIONS:

Increase lateral lines to 5" for first 600 feet of each lateral. Operate on 11 hour schedule.





CAN SPACING AT EVALUATION LOCATION

PROCEDURE:

1. Determine operating pressure at pivot and gpm entering system.
2. Calculate rate of speed and time to make circuit of field.
3. Set spray catch cans as shown in sketches ahead of sprinklers so one complete pass is made over cans. Set cans level and support above the vegetation. Catch cans should be calibrated so that volumetric measurements can be made. Quart oil cans are satisfactory and these hold approximately 200 cc per inch of depth. Therefore, 10 cc would be equivalent to 0.05 inch.
4. Observe the rate water enters the soil particularly at the far end of the line. If there is appreciable runoff, erosion or ponding that will damage crops, the rate is too high. Record distance from pivot to point where runoff is evident.
5. Determine if end gun operates on entire circle or at corners only.
6. After the discharge of the sprinklers is out of range of the cans, measure the water in each group of cans. Use a graduate that is divided into cc's.
7. From can catch, determine:
   a. Uniformity of distribution
   b. If applied amount will meet peak periods use needs.
8. To make evaluation, use the following:
   a. 100 gpm = 0.223 acre-inch per hour
   b. Distance traveled is 6.28 times radius to drive wheel

EXAMPLE:

1. Soil: Ankeny fine sandy loam on 5% slope; Intake Family 1.5 (Irrigation plan)
2. Crop: Corn (field observation)
3. Operating pressure at pivot: 72#/sq. in. (Pressure gauge reading)
4. Water supply: 975 gpm (Meter on system)
5. System length: 1,300 ft with radius to outside drive wheel 1,250'. (System details)

6. Time to travel 100': 65 minutes (timed)
7. End gun is used in corners only (observed)
8. Average catch in cans (quart oil cans were used so 10 cc = 0.05 inch):

Group #1: 230 cc or 1.15 inches
Group #2: 210 cc or 1.05 inches
Group #3: 190 cc or 0.95 inches
Group #4: 200 cc or 1.00 inches
Group #5: 180 cc or 0.90 inches

Cans at end of system

Group #1: 200 cc or 1.00 inches
Group #2: 180 cc or 0.90 inches
Group #3: 140 cc or 0.70 inches
Group #4: 90 cc or 0.45 inches
Group #5: 40 cc or 0.20 inches

200 cc = 1 inch. Therefore, 10 cc = 0.05 inch.

9. There is no appreciable ponding or runoff.

SOLUTION:

1. Rate of travel is

$$\frac{100}{65} = 1.54 \text{ ft/min.}$$

2. Travel distance for 1,250' radius = 6.28 (1,250) = 7,850 ft.

3. Travel time in hrs. =

$$\frac{7{,}850}{1.54\ (60)} = 85 \text{ hrs. or } 3.5 \text{ days}$$

4. Gross applied: 100 gpm = 0.223 ac. in/hr. Therefore, gross applied is 9.75 (0.223)(85) = 184.8 ac. in. 1,300' system covers area of 134 acres (Table 4-1 on page 4-21). Therefore, gross application is 184.8 ÷ 134 or 1.38 in.

5. Average catch for least catch area except end gun is 0.90 inch (item 8 above). 0.90" for 3.5 days is available supply of 0.26" day. Table 2-7 on page 2-24 indicates design use rate should be 0.28"/day so system furnishes slightly below recommended amount.

6. Application varies from 0.90 to 1.15 inches. Minimum then is about 79 percent of maximum.

7. Average amount caught is 1.01 or 73 percent of gross applied.

8. There is no problem on intake so system is satisfactory for this soil.

CHAPTER 5 - SURFACE IRRIGATION SYSTEMS

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Surface Irrigation Systems

Surface Irrigation

Irrigation water is applied directly to the soil surface either by controlled flooding or in some kind of furrow. In controlled flooding the water applied to the surface is controlled by dikes and ditches. Graded-border, level-border, contour-levee, and contour-ditch methods are different types of controlled-flooding irrigation. In the furrow method, water is applied through regularly spaced large furrows, furrows between crop rows, or closely spaced small furrows or corrugations. In general, flooding methods are used for close-growing crops and furrow methods for row crops.

Graded-Border Method

Description.--Graded-border irrigation is a form of controlled surface flooding. The field to be irrigated is divided into strips by parallel dikes or border ridges (fig. 5-1), and each strip is irrigated independently. The border strips should have little or no cross slope but should have some slope in the direction of irrigation. Each strip is irrigated by turning in a stream of water at the upper end. The stream must be large enough to spread over the entire width between the border ridges without overtopping them. Usually the stream size should be such that the desired volume of water is applied to the strip in a time equal to or slightly less than that needed for the soil to absorb the net amount required.

Adaptability.--This method is suitable for irrigating all close-growing, noncultivated, sown or drilled crops, except rice and any other crops grown in ponded water. Legumes, grasses, small grains, and mint commonly are irrigated by this method. Graded borders also are used for irrigating orchards and vineyards.

Graded-border irrigation can be used on most soils. It is best suited to soils that have a moderately low to moderately high intake rate. Usually it is not used for coarse sandy soils that have a very high intake rate because of the stringent limitations on design. Nor is it well

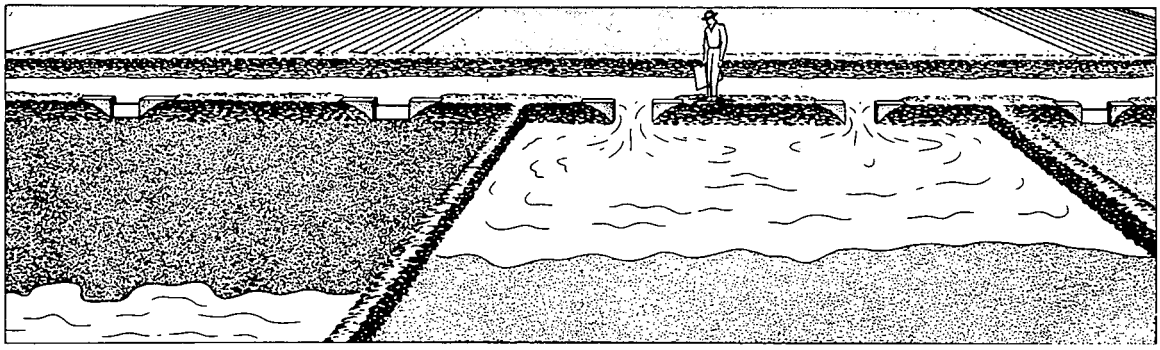

Figure 5-1 .--Graded-border irrigation.

suited to soils having a very low intake rate since, to provide adequate intake time without excessive surface runoff, the irrigating stream may be too small to completely cover the border strips. This method is best suited to slopes of less than 0.5 percent. If erosion from rainfall is not a hazard, it can be used successfully on steeper slopes if the soil intake rate is not too low. For nonsodforming crops, this method is seldom used on slopes of more than 2 percent, but it can be used on slopes as steep as 4 percent for sod crops. In humid areas the maximum slope to be irrigated by this method is about 2 percent for sodforming grasses and 0.5 percent for other crops.

Important Features.--Good to excellent field application efficiency can be obtained if the borders are well designed and installed. Labor requirements are among the lowest for all application methods, and strip width can be designed to accommodate the farm machinery used for tillage, planting, and harvesting. If surface drainage is critical, the method is an excellent means for rapid disposal of excess surface water.

Limitations.--Topography must be relatively smooth or soils deep enough for adequate leveling. In some areas, land-leveling costs may be high enough to exclude using the graded-border method. The available irrigation stream must be large enough to irrigate a border strip of practical size. Young crops may be damaged or extra tillage required on soils that bake or crust after wetting. A light irrigation of less than about 2 inches is difficult to apply efficiently.

Level-Border (Basin) Method

Description.--This method is based on the rapid application of irrigation water to a level or nearly level area enclosed by dikes that retain the water at a uniform depth until it has been taken into the soil (fig. 5-2). Level borders are similar to basins, but basins generally are as wide as they are long and level bo ders are several times longer than wide.

An overall fall of 0.2 foot in the length of the border strip is often desirable as construction tolerance to avoid reverse grades. The stream of water turned into each border should be at least twice that required for the average intake rate of the soil. If the border is level, the

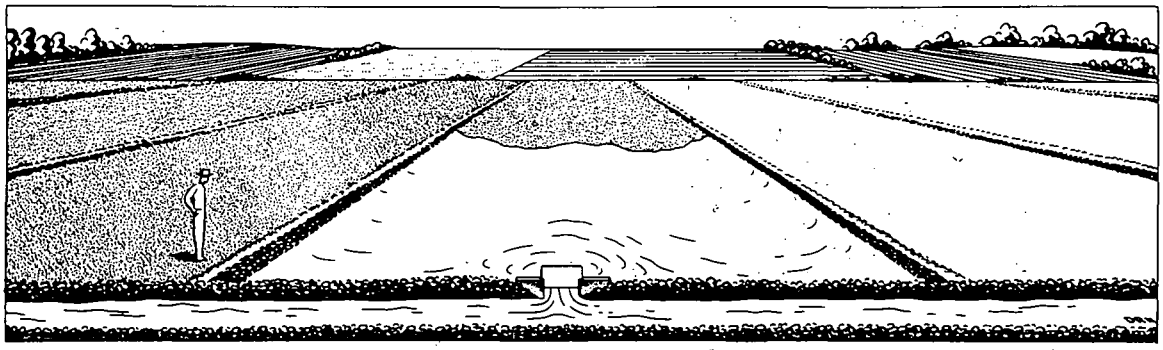

Figure 5-2.--Level-border irrigation.

irrigation stream can be turned in at any point or points around the border and at both ends if desired. If the border has a slight grade, the irrigation stream is applied at the upper end.

Adaptability.--This method is best suited to soils having a moderate to slow intake rate (2.0 intake family or less) and a moderate to high available water holding capacity. Although an efficient system for water application can be designed for soils that have a higher intake rate and a lower available water holding capacity, the borders are so small that they interfere with cultural practices and the location of delivery laterals.

Smooth, gentle, uniform land slopes are best suited to this method and give the best field layouts. One major advantage of this method is that it can be used to irrigate many different kinds of crops regardless of planting pattern. Crops such as carrots, which are adversely affected by flooding, can be planted in beds and irrigated with light applications in the intervening furrows. Row crops less susceptible to flooding can be flat-planted or bedded. Sown crops, drilled crops, and sod crops can be irrigated by using border furrows to guide the water. These wide variations can be accomplished without basic changes in layout or rate of application and still give high efficiency.

Important Features.--Many different kinds of crops can be grown in sequence without making major changes in design, layout, or operating procedures. Leaching can be accomplished without changing either layout or method of operation. Provisions for disposal or reuse of tail water are not needed although removal of excess rainfall may be necessary. Maximum use can be made of rainfall. No irrigation water is lost by runoff. This method can be adapted to automation easily or it can be operated efficiently by inexperienced labor. High application efficiency can be obtained.

Limitations.--Accurate land leveling is generally required. Border dikes must be high enough to keep the irrigation stream from overtopping the ridges. Border ridges may interfere with movement of farm machinery in border strips. On steep slopes requiring benching, drop structures, lined ditches, or pipelines may be required for adequate water control. In some areas special provisions must be made for surface drainage. In areas where wind velocity exceeds 15 to 20 miles per hour, it may be difficult to apply irrigation water if the wind direction is opposite to the direction of water flow in the border strip. Sets must be changed often. Maintenance of a level surface is essential to efficient operation, which may require changing tillage operations or using special tools, or both.

Contour-Levee Method

Description.--This method is a modification of the contour-border or basin method. Areas bounded by small contour levees and cross levees are completely flooded (fig. 5-3). Water applied at a rate considerably in excess of the intake rate of the soil spreads rapidly over the area and is allowed to remain until it has infiltrated the soil to the

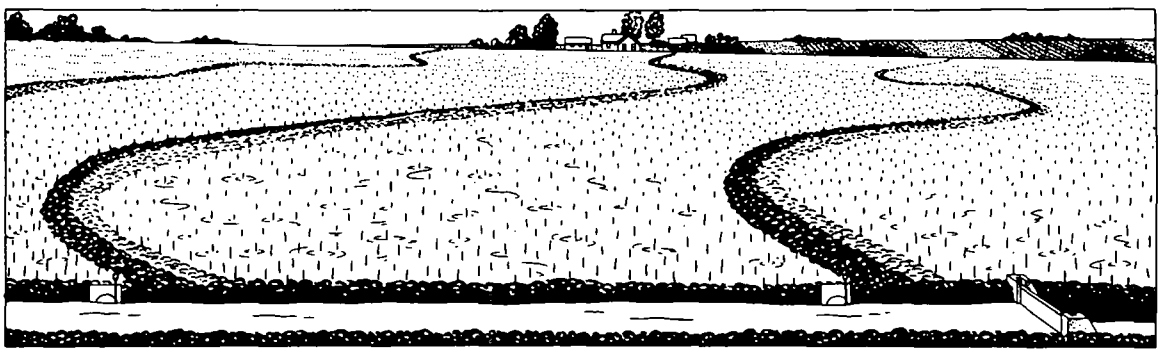

Figure 5-3.--Contour-levee irrigation.

desired depth. If the irrigation is for soil-moisture replenishment, the excess water is then drained off immediately. If the irrigation is for weed control on riceland, the water is impounded at a minimum depth of 3 inches and a maximum depth of 8 inches or less for several weeks.

Size of the unit area depends on the size of the available irrigation stream, soil intake characteristics, and topography of the field. Generally a stream of 1 cubic foot per second is required for each 2 acres for rapid flooding. Drainage is provided by placing pipe culverts in the drainageways through each levee. Water is held at the desired level by small weir-type spillways in the levees, allowing excess water from one area to spill over into the area immediately below.

Adaptability.--For successful contour-levee irrigation, soils should be medium to fine textured (0.5 intake family or less). For rice the soil should have a saturated permeability rate of 0.01 inch or less per hour or have a restricting layer of this rate just below the crop's root zone. The surface should be smooth and reasonably uniform and have a maximum slope of 1 percent, but slopes of less than 0.5 percent are preferred.

The contour-levee method is particularly suited to rice and can be used for irrigating cotton, corn, soybeans, small grains, pasture grasses, and hay crops. The crop to be irrigated must be able to stand in water for 12 hours or more without damage. Irrigation water must be available at a rate that permits rapid flooding of the areas enclosed by the levees. A minimum stream of 0.5 cubic foot per second per acre for the largest of the areas should be available.

Important Features.--Uniform distribution of irrigation water is easily obtained. A field application efficiency of 80 percent or more can be obtained with a well-planned and well-operated system. Although excess water must be drained, there is usually opportunity to reuse it on areas of lower elevation. Tail-water or runoff losses are limited to the water removed from the lowest area in the field. Since maximum use can be made of any rainfall, seasonal irrigation requirements are reduced to a minimum.

Adequate surface drainage facilities are an essential part of this system, and they can be provided at little extra expense. Generally the same facilities are used to apply water and to remove it. The amount of labor required is low compared with that required for most other methods. The controls are simple and easily operated, and irrigators with little experience can handle large irrigation streams. If only a moderate amount of land smoothing or leveling is needed, the initial cost is low compared with that of most other acceptable methods. The cost of water control structures is comparable to that of the least expensive structures used in other surface methods.

Limitations.--This method is not generally suitable for use on soils of moderate to very rapid permeability. Irrigations of less than 2 inches are difficult to apply. Large irrigation streams are required. Irrigation water must be of good to excellent quality since the slowly permeable soils to which the method is suited accumulate salts rapidly and are difficult to leach. Land smoothing or leveling is usually required for uniform distribution of irrigation water, drainage, and operation of farm equipment. Many crops cannot be successfully irrigated if they are susceptible to damage by flooding at any stage of growth. Levees may be damaged extensively by waves if water must be applied before vegetation is established.

Contour-Ditch Method

Description.--Contour-ditch irrigation is a form of controlled surface flooding. Irrigation water is distributed from ditches running across the slope approximately on the contour (fig. 5-4). Water is diverted from the ditches by temporary dams. As the water rises, it is discharged through controlled openings in the ditch bank, by siphon tubes, or over a uniformly graded lower lip of the ditch. Water flows as an unconfined sheet down the slope from one contour ditch to the next, and runoff is collected in lower ditches for reuse. Water is applied to successive strips between ditches until the field has been irrigated. The width covered by each setting of the dams depends on the stream size available. A stream of 1 cubic foot per second usually covers a strip about 100 feet wide. The spacing between contour ditches (80 to 300 feet) is governed by topography, soil intake rate, and average net irrigation application.

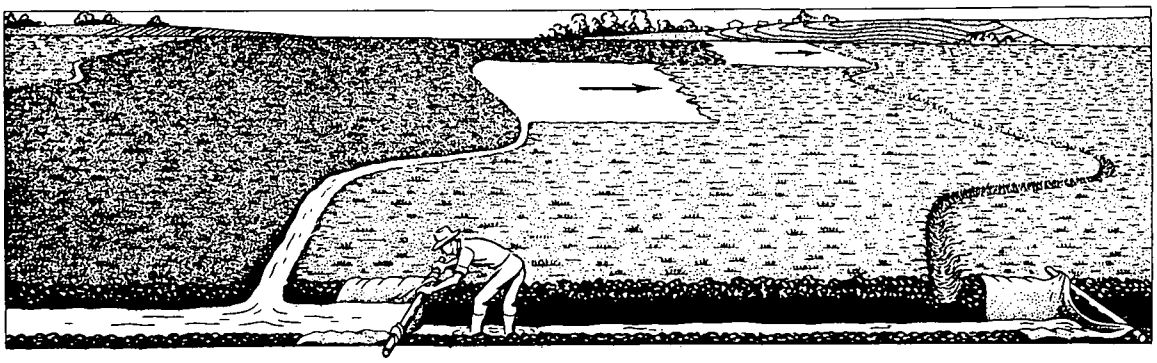

Figure 5-4.--Contour-ditch irrigation.

Adaptability.--This method is suitable for irrigating all close-growing, noncultivated crops except those grown in ponded water. Legumes, grasses, and small grains are the crops commonly irrigated by this method. Contour-ditch irrigation can be used for soils in the 0.1 to 3.0 intake families. Slowly permeable soils permit the widest spacing between ditches, and the application efficiency for a low net irrigation is high. Light-textured soils require close spacing of contour ditches, and the application efficiency is low.

This method is suited to slopes ranging from 0.5 to 15 percent. If erosion from rainfall is a hazard, the maximum slope is 4 percent. If soils and topography permit land leveling, contour ditches are seldom used on slopes of less than 1 percent. The maximum slope for moderately light to coarse textured soils is 4 percent. On slopes of 2 to 4 percent, if erosion from rainfall is a hazard, this method can be used only for sodforming crops.

Important Features.--Installation costs are among the lowest for all application methods. Little surface preparation is required on irregular topography. For annual crops the ditches can be easily filled to facilitate harvesting.

Limitations.--Irrigation efficiency is generally low. With careful management an application efficiency of 50 to 65 percent is possible. Small streams are not easily used. The spacing between ditches may vary considerably, causing different lengths of run. Extra labor is required for adjusting sets to get the proper depth of application and to reuse waste water. The close and irregular spacing between ditches hampers harvesting, especially of hay crops. Young crops may be damaged on soils that bake or crust. If rainfall erosion is a hazard, ditches cannot be installed until a crop is established, which eliminates the possibility of preplant irrigations.

Graded-Furrow Method

Description.--Graded furrows are small channels having a continuous, nearly uniform slope in the direction of irrigation (fig. 5-5). They are used in irrigating cultivated crops planted in rows. There are one or more furrows between crop rows except for bedded crops, in which the

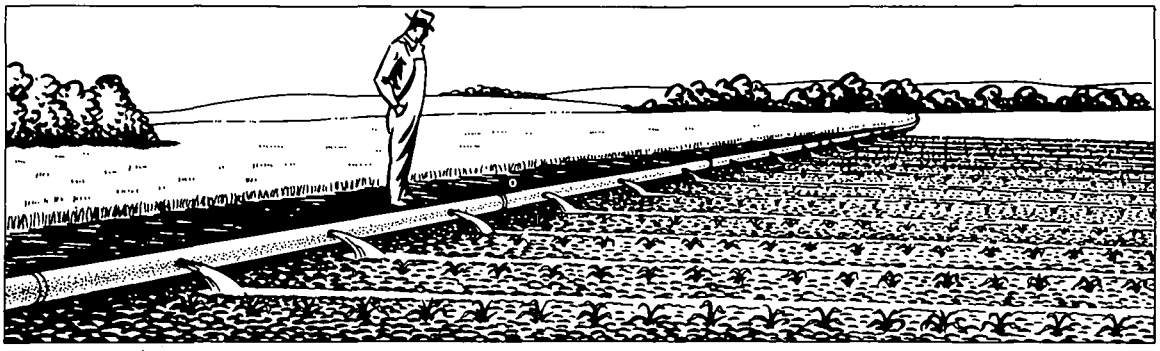

Figure 5-5.--Graded-furrow irrigation.

Surface Irrigation - Graded Furrows

furrows are along each pair of rows. Size and shape of the furrows depend on the crop grown, equipment used, and spacing between crop rows.

Water flowing in the furrows soaks into the soil and spreads laterally to irrigate the areas between furrows. The length of time that water must be run in the furrows depends on the amount of water required to refill the root zone, intake rate of the soil, and rate of lateral spread of water in the soil. For most soils,the initial irrigating streams must greatly exceed the intake rate to advance rapidly. Therefore, when water reaches the lower end of the run, the streams must be adjusted or cut back to prevent excessive waste from surface runoff or provisions must be made to recover tail water. But for low-intake-rate soils that crack when dry, it is not usually necessary to cut back the streams.

Adaptability.--The graded-furrow method can be used to irrigate all cultivated crops planted in rows, including orchard and vineyard crops as well as all field and truck crops. Graded furrows can be used on all soils except sands that have a very high intake rate and provide very poor lateral distribution of water between furrows. But they must be used with extreme care on soils that have high concentrations of soluble salts. To keep excessive amounts of toxic salts from accumulating in the areas between furrows, it may be necessary to use some surface-flooding method to leach salts from the root zone before this method can be used successfully.

This method is best suited to sites where the furrow grade does not exceed 1 percent. But in areas where erosion from rainfall is not a problem, the grade can be as much as 3 percent. In areas of intense rainfall, the furrow grade may need to be reduced to 0.5 percent or less to minimize the erosion hazard. On smooth, uniformly sloping fields, crops can be planted across the slope to reduce the furrow grade. Furrows also are used on graded benches built across the slope.

Important Features.--Both large and small irrigating streams can be used by adjusting the number of furrows irrigated at any one time to fit the available flow. Therefore, any type of water delivery, from continuous flow to full demand, can be used. Field efficiency is high if water management is good. In areas where surface drainage is necessary, the furrows can be used to dispose of runoff from rainfall rapidly.

Limitations.--Labor requirements for the graded-furrow method are high. Flow into each furrow must be carefully regulated for uniform water distribution and minimum waste. Fields must be well leveled and facilities for collecting and disposing of surface runoff must be installed. Also, the method is not suitable for applying the very light irrigations needed for seed germination or for very shallow rooted crops grown on soils with a high intake rate.

Contour-Furrow Method

Description.--The contour-furrow method is similar to the graded-furrow method in that irrigation water is applied by furrows, bu the nearly level furrows carry water across a sloping field rather than down slope

(fig. 5-6). The contour furrows are curved to fit the land surface. They have just enough grade to carry the irrigation stream. Head ditches or pipelines are run downhill or slightly across the slope to feed the individual furrows.

Adaptability.--This method can be used on most sloping soils except light sandy soils and soils that crack. The ridges between furrows in sandy soils may break and wash out, overloading the furrow below, which also breaks. This may continue all the way down the slope, causing heavy erosion damage. Soils that crack provide channels for water, causing similar downslope furrow breaks. This method is particularly suited to fields of uniform slope in both directions because most of the furrows can run completely across the slope and there need be few point rows.

The contour-furrow method can be used for nearly all cultivated crops planted in rows. In arid sections deep-furrowed row crops grown on medium- and fine-textured soils can be irrigated if the slope does not exceed 6 percent. On light-textured soils, the slope must not exceed 4 percent because of the danger of furrow breaks. For shallow-furrowed crops, the slope must not exceed 3 percent. For citrus and deciduous fruits, cane berries, vineyards, and nut trees, the slope can be steeper since the furrows are not disturbed by cultivation.

Important Features.--The contour-furrow method can be used to irrigate safely land too steep for downhill furrows, thus reducing the erosion hazard. Good distribution of water is possible because large irrigating streams can be used in the nearly level furrows and water reaches the end of the furrows quickly. This also reduces the time of irrigating. Good efficiency can be attained if the system is properly laid out and good water management practices are followed.

Limitations.--This method must be watched carefully to guard against furrow overflow and washout. In areas of intense rainstorms, rainfall probably causes more breakthroughs than irrigation water. The runs should be short enough to dispose of the runoff safely without breaking the furrow. Grassed waterways and structures are usually needed to carry

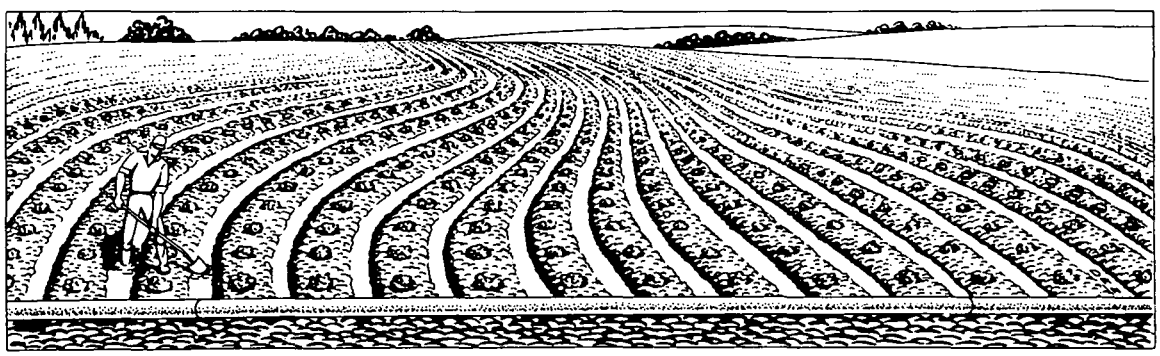

Figure 5-6.--Contour-furrow irrigation.

surplus water down the slope. For a crop like corn, all furrow breaks must be repaired by hand after the corn is laid by. Contour-furrow irrigation, used in conjunction with parallel terraces, provides additional insurance against breakthroughs.

Head and tail-water ditches must be protected because they run downslope and generally the grade is erosive. Considerable time is necessary to lay out a field, and planting and tillage must be done very carefully. Equipment used in planting, cultivating, and harvesting must turn on the crop at the end of point rows.

Level-Furrow Method

Description.--Level furrows are small channels without grade formed by farm equipment and used to irrigate crops planted in or between the furrows (fig. 5-7). The level-furrow method of water application requires the rapid introduction of irrigation water. A stream as large as the furrow can contain is turned into the furrow until the gross application has been made. The water, which is at uniform depth throughout the furrows, stands until absorbed by the soil. Lateral or capillary movement of water through the soil distributes the water to areas between furrows.

Adaptability.--The level-furrow method is best suited to soils having a moderate to slow intake rate (2.0 intake family or less) and a moderate to high available water holding capacity. The best field layouts for level furrows are on smooth uniform slopes. Row crops are the crops most easily irrigated by level furrows, but drilled or sown crops can be irrigated effectively if the soil has been furrowed and ridged before planting. In areas where rainstorms occur in such intensity and duration that the water-storage capacity of the furrow may be exceeded, border dikes are also needed.

Important Features.--The amount of water applied can be adjusted to meet seasonal variations by changing duration of application or size of furrow stream, or both. No change in layout is needed. High application efficiency can be obtained with this method if it is properly designed and operated. No irrigation water need be lost through runoff.

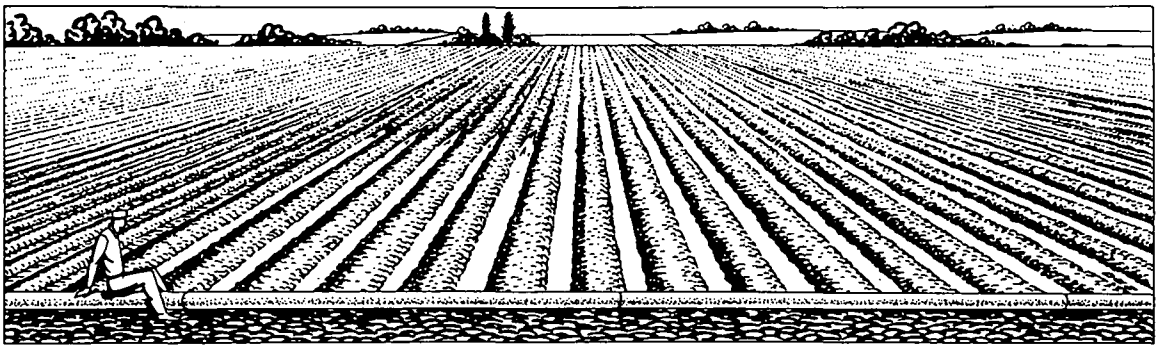

Figure 5-7.--Level-furrow irrigation.

Unless winds of high velocity affect the advancing stream, the field ditches or other conveyance structures can be spaced at twice the design furrow length since water can be introduced at both ends of the furrows. This reduces cost of constructing and maintaining the delivery system, and farm machinery can travel farther before turning. Maximum use can be made of rainfall even if storm intensity exceeds the intake rate. Provisions for disposal or reuse of tail water are not needed. Leaching can be easily accomplished. This method can be automated easily.

Limitations.--In areas where wind velocity exceeds 15 to 20 miles per hour, it is difficult to apply irrigation water if the wind direction is opposite to the direction of water flow in the furrow. Since wind erosion is usually a problem in such areas, row and furrow length should be normal to the prevailing wind direction if practical. If the furrow length is parallel to the prevailing wind direction, water should be applied at the upwind end of the furrows.

Furrow capacity must be large enough to control stream flow. Furrows should be able to contain approximately one-half the volume of the net irrigation application. Sets must be changed often. For efficient operation of a system using this method of water application, it is essential that tillage operations maintain the surface topography and the furrow shape and cross section.

Drip (Trickle) Irrigation

Drip irrigation is characterized by distribution of water at low pressure, not more than 15-20 psi, directly on the ground and near each plant. The drop of water is deposited from a device called an emitter. There is enough friction loss through the emitter to allow the water to be discharged as a "drip".

Some advantages claimed by proponents of drip irrigation are:

1. Water savings.
2. Reduced amounts of fertilizer used if the plant food is distributed and applied through the irrigation system.
3. Labor savings.
4. Easier weed control.
5. Possibility of using high salinity water without damaging the crop.
6. Higher quality crops.
7. More uniform fruit that matures earlier.

Water is saved because it is applied at the daily rate that the plant is using it and is applied only to the active root zone. The area of a field wetted with drip irrigation is much less than the area wetted by other irrigation methods. Therefore, the evaporation losses are greatly reduced. Little if any water is lost to deep percolation from the drip method.

Much of the problems concerned with drip irrigation have been of a mechanical nature. Orifice stopage and unequal pressure distribution have been the principal problems. Extensive filtering is required for most drip irrigation systems.

Costs of installing and operating a drip system are high compared to other methods, especially where water supplies are plentiful and low income crops are being produced.

CHAPTER 6 - SPECIAL USE OF SPRINKLER IRRIGATION EQUIPMENT

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CHAPTER 6

Waste Disposal by Sprinklers

Disposing of waste on land is not a new concept. Crops have been grown for centuries on land used for spreading manure and sewage. These materials were regarded as fertilizers, not wastes. Many kinds of grasses, vegetables, legumes, and woody plants have been subjected to waste disposal, grass seems to be the most effective vegetation for this purpose. Many species of grass possess a high water use factor combined with abundant root production. The roots and sod retard runoff and enhance infiltration. The plant leaves pump water back into the atmosphere. Wastes become pollutants when they are introduced into the air, water, or soil in excessive amounts or otherwise become offensive in the environment.

The interaction of soils, plants, and water must be thoroughly considered before a sprinkler disposal system is installed and expected to operate successfully.

Generally, an existing irrigation system can be utilized to apply effluent to the land. The sprinkler nozzle will need to be large enough to pass the solids that are in the effluent. One of the major problems associated with sprinkler application is the corrosive nature of the effluent.

Nitrogen seems to be the most critical of the nutrients in livestock waste and, therefore, the controlling factor. When livestock waste is applied to cropland the total nitrogen produced by the animal can be used as a guide for determining the total application to each acre without excess buildup of nitrates.

The depth of application should be such that polluted waters will not be forced into groundwater supplies or runoff will occur to pollute surface water. The depth of application will be determined by the specific pollution potential, the intake rate of the soil, depth of soil, crop use of water, and climatic conditions such as temperature and rainfall. Generally, when slurry waste is applied to the land, it is best to plan for an application of one (1) inch or less. This is suggested because solids in the material soon form a sealing layer on the surface and severely restrict intake. If allowed to dry, this layer will flake and crack and again permit normal intake. If lagoon or holding pond effluent disposal is the primary purpose, an application depth up to 2.0 inches may be satisfactory.

The total depth of effluent application per season can be determined when the concentration of total N in the effluent water is known.

Application rates must be selected to fit the sprinkler intake rate of the soil. Application rates should not exceed the rates shown in Table 3-4 of this guide or the values given below for heavier soils

not listed in Table 3-4.

Table 6-1

Soil	With Cover	Bare
Clay soils; very poorly drained	0.3 in./hr.	0.15 in./hr.
Silty surface; poorly drained clay and clay pan soils	0.4 in./hr.	0.25 in./hr.

These rates apply to soils with slopes less than 2 percent, the soil is dry (no precipitation in previous two (2) days during the growing season) and applied in light applications ($\frac{1}{2}$ to 1"). When effluent disposal is planned, especially on the heavier soils, extreme care must be exercised to plan drainage systems that will dispose of excess runoff without causing erosion or pollution. Examples of this might be to divert water from higher land and provision for spreading and overland flow of the excess runoff from the disposal area through a grass buffer or filter zone before access to surface waterways are reached.

Some of the critical considerations of sprinkler application of effluent follows:

1. Excessive rate or volume of application may result in runoff and pollution of surface water.

2. Excessive application depths may result in pollution of groundwater especially on highly permeable soils.

3. Effluent may contain toxic or detrimental materials to soil or plants.

4. Odors from sprinkling may be obnoxious.

5. Effluent is highly corrosive and may shorten the useful life of equipment.

6. Solids from the effluent may coat plant leaves and reduce photosynthesis.

The system should be operated with clear water for at least 15 minutes to wash the system as well as remove solids off of the plants.

Water driven self-propelled systems should not be used for waste disposal.

Frost Protection By Sprinkling

Sprinkler irrigation systems can and are being used for frost protection; however, the ordinary system is limited because of the area it can cover with any one setting of the lateral lines. Therefore, for adequate protection of most areas, it is necessary to add lateral lines and

sprinklers at the predetermined spacing so that the entire field can be covered with a fine mist of water during freezing temperatures. Therefore, only the permanent or set type sprinkler systems can be utilized for frost protection. The center pivot and other moving systems cannot be adapted to cover an entire field at one time.

For frost protection, the wetted area from one sprinkler should just meet or overlap a few feet of the wetted area from another. Application rates of about 0.10 inch/hour are used for frost protection. The rate must be low to avoid exceeding the water holding capacity of the soil and to avoid excess ice buildup on the crop.

In general, crops can be protected from frost to 27 or 28°F and works best to prevent radiation cooling. It is more difficult to prevent damage when the cooling is associated with the passage of a cold front with associated wind conditions.

Frost protection is provided to a plant if water is present on the leaf surface and the latent heat given up by the water is absorbed by the plant. The temperature of the plant or ice formed on it will drop below 32°F as long as the coating of ice is kept wet.

Application of Fertilizers

Dissolving soluble fertilizers in water and applying the solution through a sprinkler system is quick, economical, easy, and effective. A minimum of equipment is required, and once the apparatus for adding the fertilizer to the irrigation water is set up, the crop being irrigated can be fertilized with less effort than is required for mechanical application. In fact, both irrigation and fertilization can be accomplished with only slightly more labor than is required for irrigation alone, especially if irrigation and fertilizer application can be scheduled to coincide.

The uniformity of the fertilizer application is only as good as the uniformity of water application. However, close control over the placement depth of fertilizer is possible.

Continuous move systems require a constant flow and concentration of nutrients into the system in order to get even distribution within a field. Set type systems permit variations in the concentration and flow into the system since all portions of a field is being treated for a specific time period and at any instant all will be receiving the same concentration.

The system should be operated at least 30 minutes with clear water to rinse fertilizer from the system and off of plant foliage.

Fertilizers may be injected into the sprinkler system by any one of several methods. The simplest is to introduce the fertilizer at the suction side of a certrifugal pump. Another common method is to introduce the fertilizer solution with gear pump discharging into the main line of the system.

University of Minnesota Agricultural Extension Service Bulletin M-152 dated 1970, entitled "Nitrogen Fertilizer Injection", goes further into when to apply nitrogen, how much, and how to calculate rates for set type and continuous move systems.

CHAPTER 7 - SCHEDULING IRRIGATION

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Moisture Accounting Method

Moisture accounting is a useful method for scheduling irrigations by providing a running balance of available moisture in the effective root zone. The method is based upon two important principles:

1. If there is an adequate supply of available moisture in the soil, the consumptive use rate for any given crop depends primarily on climatological conditions.
2. If the moisture content of a soil is known for any given time, the moisture content at any later time can be computed by adding water gains (effective rainfall and/or irrigation) and subtracting water losses (consumptive use) during the elapsed period.

Effectiveness of the method depends upon the accuracy with which available moisture holding capacity of the soil, rainfall, net irrigation amounts and evapotranspiration values are determined. In humid areas, occasional rainfall will refill the root zone to field capacity, thereby preventing an accumulation of errors that might affect the accuracy of the method. One of the problems in using this method is making a reliable estimate of the daily consumptive-use rate for the crop grown. If research has established an average daily consumptive-use rate for the same crop in nearby areas, this rate should be used. Generally, such data are not available and the consumptive-use rate must be estimated. To arrive at an accurate estimate of the consumptive-use rate for any given day, it is necessary to correct the average rate for the weather conditions of that day.

The four principal climatological factors that influence a change in consumptive use for any given day are: (1) Average temperature, (2) percentage of possible sunshine hours or sunshine duration, (3) average relative humidity, and (4) average wind speed. Of the four factors, temperature and sunshine duration are by far the most significant. Temperature can easily be measured on the site with a reliable thermometer. The average of the high and low readings for a 24-hour period can be taken as the average temperature for that day. The same readings can often be obtained from a nearby Weather Bureau station. Either sunshine duration or cloudiness can be estimated visually with sufficient accuracy for ordinary farm irrigation. Because of the earth's movement and axial inclination, the hours of daylight during the summer are much greater in the higher latitudes than at the equator. Since the sun is the source of all energy used in crop growth and evaporation of water, this longer day may allow plant transpiration to continue for a longer period each day and to produce an effect similar to that of lengthening the growing season.

Relative humidity and wind speed are of minor significance and can be ignored without seriously affecting the data. They are difficult to measure, and measurements are not available from the Weather Bureau in most areas.

The modification necessary to reflect variations in temperature and sunshine can be taken from Table 7-3. The applicable average consumptive use rate for any particular date can be taken from Table 7-1 and 7-2.

As previously stated, another factor which causes consumptive use to vary widely throughout the growing season is the plant itself. Stage of growth is a primary variable that must be recognized since it is obvious that plants in the rapid growth stage will use water at a more rapid rate than will seedlings. Curves have been developed for each of the crops. Crop coefficients can be selected for growth stage from the curves found in the appendix.

The moisture accounting method requires a daily measurement of rainfall at the site. A small, inexpensive rain gage is satisfactory if it is read carefully. It should be located away from buildings, trees, and high vegetation so that it accurately measures the amount of rainfall. It should be read early each morning.

The moisture accounting method is intended for use in scheduling irrigations and accounting for rainfall events. It will not necessarily produce seasonal values numerically equivalent to those found in Tables 2-1A through 2-6C which are based on long term averages of climatic data. The moisture accounting method is expected to produce the best estimate of consumptive use for short term periods within the growing season.

TABLE 7-1

Average Daily Consumptive Use Based on Average Temperatures

	CLIMATIC AREA 1		CLIMATIC AREA 2		CLIMATIC AREA 3	
Midpoint of Period Date	Average Temp. at Mid-Point (°F)	Potential Consumptive Use "u_p" (in/day)	Average Temp. at Mid-Point (°F)	Potential Consumptive Use "u_p" (in/day)	Average Temp. at Mid-Point (°F)	Potential Consumptive Use "u_p" (in/day)
4/15	41.2	0.055	43.5	0.057	39.9	.045
4/21	43.2	0.062	46.0	0.070	42.0	.055
4/27	46.0	0.075	48.5	0.083	44.6	.066
5/3	48.7	0.088	51.2	0.098	47.4	.078
5/9	51.5	0.102	54.0	0.112	50.0	.080
5/15	54.0	0.116	57.0	0.127	52.5	.105
5/21	56.3	0.127	58.8	0.141	54.2	.118
5/27	57.9	0.138	60.5	0.154	56.2	.133
6/2	59.5	0.149	62.5	0.167	58.0	.145
6/8	61.0	0.159	64.2	0.178	60.0	.155
6/14	63.0	0.172	66.0	0.189	62.0	.165
6/20	64.6	0.181	67.2	0.200	62.8	.173
6/26	66.0	0.192	68.5	0.208	64.0	.182
7/2	67.4	0.202	69.5	0.217	65.0	.187
7/8	68.7	0.212	71.0	0.224	66.0	.193
7/14	70.0	0.220	72.0	0.231	67.0	.198
7/20	71.0	0.225	72.8	0.236	67.8	.202
7/26	71.5	0.228	73.5	0.240	68.3	.203
8/1	71.4	0.220	73.2	0.234	68.1	.198
8/7	70.5	0.206	72.0	0.223	66.9	.185
8/13	69.0	0.190	71.0	0.208	65.3	.171
8/19	66.8	0.175	69.0	0.190	63.8	.158
8/25	64.5	0.160	66.8	0.175	62.0	.145
8/31	62.6	0.145	64.7	0.159	60.0	.132
9/6	60.5	0.130	62.5	0.143	58.2	.120
9/12	58.5	0.115	60.2	0.127	56.4	.107
9/18	56.3	0.100	58.0	0.112	54.1	.094
9/24	54.0	0.088	55.5	0.098	52.0	.083
9/30	52.0	0.076	53.5	0.085	50.0	.072
10/6	49.5	0.067	51.0	0.075	47.8	.064
10/12	47.0	0.058	48.8	0.065	45.7	.054
10/18	44.0	0.050	45.5	0.055	43.0	.046
10/24	40.0	0.045	42.0	0.050	39.5	.040

TABLE 7-2

Average Daily Consumptive Use Based on Average Temperatures

	CLIMATIC AREA 4		CLIMATIC AREA 5		CLIMATIC AREA 6	
Midpoint of Period Date	Average Temp. at Mid-Point (°F)	Potential Consumptive Use "u_p" (in/day)	Average Temp. at Mid-Point (°F)	Potential Consumptive Use "u_p" (in/day)	Average Temp. at Mid-Point (°F)	Potential Consumptive Use "u_p" (in/day)
4/15	42.8	.054	45.9	.066	46.2	.066
4/21	45.2	.065	48.5	.077	48.5	.078
4/27	48.0	.078	51.0	.090	51.0	.091
5/3	50.5	.092	53.5	.105	53.5	.105
5/9	53.0	.105	56.0	.120	56.0	.120
5/15	55.5	.119	59.0	.134	58.5	.134
5/21	57.5	.132	60.5	.14	60.5	.147
5/27	59.4	.145	62.5	.163	62.2	.153
6/2	61.5	.160	64.5	.178	64.2	.175
6/8	63.2	.172	66.5	.192	66.0	.188
6/14	65.2	.185	68.5	.205	68.0	.200
6/20	66.2	.194	69.7	.215	69.0	.210
6/26	67.5	.203	70.8	.225	69.9	.218
7/2	68.6	.211	72.0	.232	70.8	.225
7/8	69.8	.216	73.3	.240	71.7	.231
7/14	71.0	.220	74.5	.245	72.8	.235
7/20	71.5	.222	75.2	.247	73.3	.237
7/26	71.5	.219	75.5	.249	73.5	.238
8/1	71.0	.213	75.3	.243	73.4	.230
8/7	70.2	.204	74.0	.230	72.2	.220
8/13	69.0	.193	72.3	.217	71.0	.208
8/19	67.6	.180	70.5	.202	70.0	.194
8/25	65.5	.165	68.7	.187	68.0	.180
8/31	63.6	.150	67.8	.172	66.4	.165
9/6	61.7	.135	66.0	.158	64.8	.150
9/12	59.8	.122	63.9	.144	63.0	.135
9/18	57.5	.108	62.0	.130	61.0	.122
9/24	55.4	.095	59.7	.115	58.8	.109
9/30	53.0	.085	57.5	0.100	56.3	.096
10/6	51.0	.074	54.9	.088	54.0	.085
10/12	48.7	.065	52.5	.076	51.7	.075
10/18	46.0	.055	51.3	.066	48.5	.065
10/24	42.3	.048	47.5	.056	45.0	.057

TABLE 7-3

Table of modifying values for use with Table 7-4 when temperature or duration of sunshine deviates from the long-term average conditions.

Observed deviation from the mean temperature for the day.	Hours of Observed Sunshine		
	0-6	6.1-11	11.1-15
-10°F	-0.032	-0.006	+0.014
-5°F	-0.029	-0.003	+0.017
0°F	-0.026	Normal-use value from table.	+0.020
+5°F	-0.023	+0.003	+0.023
+10°F	-0.020	+0.006	+0.026

TABLE 7-4
Moisture Balance Sheet

Farm: Sunny Acres Farm Month: May Soil Type(s) Anoka

County: Washington Crop: Corn, grain AWC: 5.2

Climatic Area: 4 Irrigate When Balance is: 2.6

Growing Season Length: 130 days

Date (1)	Days After Planting (1)	Percent of Growing Season (2)	K_c, Crop Coefficient (3)	Observed Sunshine (4)	Observed Average Daily Temp. (5)	Adjustment Factor to Potential ET (6)	Adjusted Potential ET (7)	Actual ET Col. (3) x Col. (7) (8)	Rainfall (9)	Net Irrigation Requirement (10)	Daily Balance (11)	Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
		%		Hrs.	°F.				in.	in.	in.	
						Balance Brought Forward					2.6	
1												
2												
3												
4												
5												
6												
7												
8												
9											5.00	Estimated
10	1	1	.44	2	49	-.029	.076	.03	.79		5.20	Total 5.79;
11	2	1	.44	3	56	-.026	.079	.03	.09		5.20	Add rainfall to
12	3	2	.45	7	47	-.003	.107	.05			5.15	balance when it
13	4	3	.45	2	41	-.032	.078	.04	.36		5.20	exceeds 0.2 in.
14	5	4	.45	4	48	-.029	.090	.04	.02		5.16	
15	6	4	.45	3	49	-.029	.090	.04	.02		5.12	
16	7	5	.46	5	60	-.023	.097	.04	.02		5.08	
17	8	6	.46	8	57	- - -	.120	.06			5.02	
18	9	7	.47	8	55	- - -	.120	.06			4.96	
19	10	8	.48	9	62	+.003	.128	.06			4.90	
20	11	8	.48	8	73	+.006	.138	.07			4.83	
21	12	9	.49	5	67	-.020	.112	.05	.08		4.78	
22	13	10	.49	6	59	-.026	.109	.05			4.73	
23	14	11	.50	6	52	-.032	.103	.05			4.68	
24	15	12	.51	7	50	-.006	.134	.07			4.61	
25	16	12	.51	7	50	-.006	.134	.07			4.54	
26	17	13	.52	8	56	-.003	.142	.07			4.47	
27	18	14	.52	8	62	- - -	.145	.08			4.39	
28	19	14	.52	9	68	+.006	.151	.08			4.31	
29	20	15	.53	8	69	+.006	.156	.08			4.23	
30	21	15	.53	4	60	-.026	.124	.07	.50		4.66	
31	22	16	.54	6	60	-.026	.129	.07			4.59	
Total:								1.25		- -		

TABLE 7-4
Moisture Balance Sheet

Farm: Sunny Acres Farm Month: June Soil Type(s) Anoka

County: Washington Crop: Corn, grain AWC: 5.2

Climatic Area: 4 Irrigate When Balance is: 2.6

Growing Season Length: 130 days

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	
Date	Days After Planting	Percent of Growing Season	K_c, Crop Coefficient	Observed Sunshine	Observed Average Daily Temp.	Adjustment Factor to Potential ET	Adjusted Potential ET	Actual ET Col. (3) x Col. (7)	Rainfall	Net Irrigation Requirement	Daily Balance	Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
		%		Hrs.	°F.				in.	in.	in.	
						Balance Brought Forward					4.59	
1	23	18	.56	8	54	-.006	.154	.09	.12		4.50	Less than 0.2 rain
2	24	18	.56	8	58	-.003	.157	.09	--		4.41	
3	25	19	.57	7	73	+.006	.166	.09	1.26		5.20	Total 5.58
4	26	20	.58	9	73	+.006	.166	.10	.17		5.20	Allow free wateruse
5	27	21	.59	12	74	+.026	.196	.12	--		5.20	Allow free water us
6	28	21	.60	8	60	-.003	.169	.10	1.59		5.20	Total 6.79
7	29	22	.60	9	64	----	.172	.10	--		5.20	Allow free water
8	30	23	.61	9	66	----	.172	.10	--		5.20	use while draining
9	31	24	.62	8	61	----	.172	.11	.76		5.20	Total 5.96
10	32	25	.63	8	61	----	.172	.11	.39		5.20	Total 6.35
11	33	25	.64	9	60	-.003	.169	.11	--		5.20	Allow free water use
12	34	26	.65	8	60	-.003	.177	.12	.05		5.20	Less than 0.2"rain
13	35	27	.66	9	63	----	.185	.12			5.08	
14	36	28	.68	9	68	+.003	.188	.13			4.95	
15	37	28	.68	9	58	-.004	.181	.12			4.83	
16	38	29	.70	12	55	+.014	.199	.14			4.69	
17	39	30	.71	12	62	+.017	.207	.15			4.54	
18	40	31	.73	9	66	----	.190	.14	.06		4.40	Less than 0.2" rain
19	41	31	.73	9	71	+.003	.197	.14			4.26	
20	42	32	.75	9	71	+.003	.197	.15	.81		4.92	
21	43	33	.77	10	72	+.003	.197	.15			4.77	
22	44	34	.80	13	67	+.020	.217	.17			4.60	
23	45	35	.81	13	62	+.017	.214	.17			4.43	
24	46	35	.81	14	66	+.020	.223	.18			4.25	
25	47	36	.84	14	67	+.020	.223	.19			4.06	
26	48	37	.86	15	67	+.020	.223	.19			3.87	
27	49	38	.88	15	71	+.023	.226	.20			3.67	
28	50	38	.88	14	75	+.026	.229	.20			3.47	
29	51	39	.90	14	76	+.026	.229	.21			3.26	
30	52	40	.92	14	70	+.020	.231	.21			3.05	
31												
Total:								4.20				

TABLE 7-4
Moisture Balance Sheet

Farm: Sunny Acres Farm Month: July Soil Type(s) Anoka

County: Washington Crop: Corn, grain AWC: 5.2

Climatic Area: 4 Irrigate When Balance is: 2.6

Growing Season Length: 130 days

Date (1)	Days After Planting (2)	Percent of Growing Season (3)	K_c, Crop Coefficient (4)	Observed Sunshine (5)	Observed Average Daily Temp. (6)	Adjustment Factor to Potential ET (7)	Adjusted Potential ET (8)	Actual ET Col. (3) x Col. (7) (9)	Rainfall (10)	Net Irrigation Requirement (11)	Daily Balance	Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
		%		Hrs.	°F.				in.	in.	in.	
						Balance Brought Forward					3.05	
1	53	41	.94	9	78	+.006	.216	.203	.04		2.85	
2	54	42	.96	12	82	+.026	.236	.227		2.81	2.62	
3	55	42	.98	12	77	+.026	.236	.231	.08		5.20	Irrigate
4	56	43	1.00	13	72	+.023	.234	.234			4.97	
5	57	44	1.00	13	76	+.023	.239	.239			4.73	
6	58	45	1.00	14	81	+.026	.242	.242			4.49	
7	59	45	1.00	14	83	+.026	.242	.242			4.25	
8	60	46	1.02	14	87	+.026	.242	.247			4.00	
9	61	47	1.03	14	85	+.026	.242	.249			3.75	
10	62	48	1.04	9	79	+.006	.222	.231	.07		3.52	
11	63	48	1.04	9	74	+.003	.223	.232			3.29	
12	64	49	1.05	8	80	+.006	.226	.237	.30		3.35	Add 0.3" rain
13	65	50	1.05	8	84	+.006	.226	.237	.34		3.45	
14	66	51	1.06	9	76	+.003	.226	.240			3.21	
15	67	52	1.06	9	72	---	.220	.233			2.99	
16	68	52	1.06	12	77	+.023	.243	.258			2.73	
17	69	53	1.07	9	81	+.006	.226	.242	.11		2.49	Less than 0.2" rain
18	70	54	1.07	12	75	+.023	.243	.260	.03	2.97	5.20	
19	71	54	1.07	13	80	+.026	.248	.265			4.94	
20	72	55	1.08	13	78	+.023	.245	.265			4.67	
21	73	56	1.08	12	75	+.023	.245	.265	.04		4.41	
22	74	57	1.08	12	75	+.023	.245	.265			4.14	
23	75	58	1.08	9	74	+.003	.225	.243	.13		3.90	Less than 0.2" rain
24	76	58	1.08	10	77	+.003	.222	.240			3.66	
25	77	59	1.08	12	78	+.023	.242	.261			3.40	
26	78	60	1.08	12	73	+.020	.239	.258			3.14	
27	79	61	1.08	10	71	---	.219	.236			2.90	
28	80	62	1.08	9	71	---	.219	.236			2.66	
29	81	62	1.08	10	68	---	.219	.236		2.78	5.20	
30	82	63	1.08	10	67	-.003	.210	.227			4.97	
31	83	64	1.07	10	67	-.003	.210	.225			4.75	
Total:								.774		8.56		Excess = 2.15

TABLE 7-4
Moisture Balance Sheet

Farm: Sunny Acres Farm Month: August Soil Type(s) Anoka

County: Washington Crop: Corn, grain AWC: 5.2

Climatic Area: 4 Irrigate When Balance is: 2.6

Growing Season Length: 130 days

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	
Date	Days After Planting	Percent of Growing Season	K_c, Crop Coefficient	Observed Sunshine	Observed Average Daily Temp.	Adjustment Factor to Potential ET	Adjusted Potential ET	Actual ET Col. (3) x Col. (7)	Rainfall	Net Irrigation Requirement	Daily Balance	Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
		%		Hrs.	°F.				in.	in.	in.	
						Balance Brought Forward					4.75	
1	84	65	1.07	13	71	+.02	.233	.239			4.50	
2	85	60	1.07	14	62	+.014	.225	.241	.84		5.10	
3	86	66	1.07	9	56	-.009	.200	.214	1.38		5.20	Total 6.48" allow
4	87	67	1.07	4	64	-.029	.179	.191			5.20	2 days free water
5	88	68	1.07	13	70	+.02	.227	.243			5.20	use while drain-
6	89	68	1.06	13	71	+.02	.226	.240			4.76	ing
7	90	69	1.06	14	70	+.02	.226	.240			4.52	
8	91	70	1.06	10	69	---	.204	.216			4.30	
9	92	71	1.06	9	72	---	.200	.212			4.09	
10	93	72	1.05	10	72	---	.195	.205			3.89	
11	94	72	1.04	5	68	-.026	.169	.176	.36		4.07	Add 0.36" rain
12	95	73	1.03	13	72	+.02	.213	.219			3.75	
13	96	74	1.03	13	69	+.02	.213	.219			3.53	
14	97	75	1.03	10	71	---	.193	.199			3.33	
15	98	75	1.02	13	74	+.023	.216	.220			3.11	
16	99	76	1.02	5	72	-.023	.170	.173	1.79		4.73	Add 1.79" rain
17	100	77	1.01	12	68	+.02	.200	.202			4.53	
18	101	77	1.01	10	68	---	.180	.182			4.35	
19	102	78	1.01	9	72	+.003	.183	.184			4.17	
20	103	79	1.00	13	79	+.026	.206	.206			3.96	
21	104	80	1.00	13	76	+.023	.203	.203	.26		4.02	
22	105	81	1.00	10	66	---	.180	.180			3.84	
23	106	82	.99	12	62	+.017	.183	.180			3.66	
24	107	82	.99	12	67	+.020	.185	.183			3.48	
25	108	83	.98	13	73	+.023	.188	.185			3.30	
26	109	84	.98	12	74	+.023	.188	.184			3.12	
27	110	85	.97	13	60	+.017	.183	.177			2.94	
28	111	85	.97	12	62	+.017	.183	.177			2.76	
29	112	86	.96	12	63	+017	.167	.160		2.60	5.20	Irrigate 2.6"
30	113	86	.95	12	59	+.017	.167	.159			5.04	
31	114	88	.95	9	57	-.003	.147	.140	.06		4.90	Less than 0.2" rain
Total:								6.16		2.60		

TABLE 7-4
Moisture Balance Sheet

Farm: Sunny Acres Farm Month: September Soil Type(s) Anoka

County: Washington Crop: Corn, grain AWC: 5.2

Climatic Area: 4 Irrigate When Balance is: 2.6

Growing Season Length: 130 days

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	
Date	Days After Planting	Percent of Growing Season	K_c, Crop Coefficient	Observed Sunshine	Observed Average Daily Temp.	Adjustment Factor to Potential ET	Adjusted Potential ET	Actual ET Col. (3) x Col. (7)	Rainfall	Net Irrigation Requirement	Daily Balance	Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
		%		Hrs.	°F.				in.	in.	in.	
						Balance Brought Forward					4.90	
1	115	88	.96	12	53	+.014	.164	.157			4.74	
2	116	89	.94	9	52	+.020	.170	.160	.10		4.58	Less than o.2" rain
3	117	90	.93	10	50	-.006	.140	.130			4.45	
4	118	91	.93	9	55	-.003	.137	.127			4.32	
5	119	92	.93	13	55	+.017	.152	.141			4.18	
6	120	92	.93	13	58	+.017	.152	.141			4.04	
7	121	93	.91	10	61	---	.135	.123			3.92	
8	122	94	.90	12	65	+.023	.153	.138			3.78	
9	123	95	.89	12	61	+.02	.145	.129	.45		4.10	Add 0.45" rain
10	124	95	.88	5	67	-.023	.099	.087	.20		4.21	Add 0.2" rain
11	125	96	.86	9	68	+.003	.125	.107			4.10	
12	126	96	.85	9	54	-.003	.119	.101	.03		4.00	
13	127	97	.84	8	50	-.006	.116	.097	.21		4.11	Add 0.21" rain
14	128	98	.83	8	57	---	.115	.095	.14		4.01	Less than 0.2" rain
15	129	99	.82	12	61	+.023	.130	.107			3.90	
16	130	100	.80	12	58	+.02	.128	.102			3.80*	
17								1.94		0		
18												
19												
20												
21								21.06		11.16		
22												
23	* Balance exceeds 50% depletion level of 2.6 inches. Some irrigation											
24	water has been wasted. The last irrigation on August 29, could have											
25	been a lighter application to allow crop to deplete available water											
26	to 50% or lower.											
27												
28												
29												
30												
31												
Total:												

Tensiometers

Tensiometers (figure 7-1) work on the principle that a partial vacuum is created in a closed chamber when water moved out through a porous ceramic tip to the surrounding soil. Tension is measured by a water manometer, a mercury manometer, or a vacuum gage. The scales are generally calibrated in either hundredths of an atmosphere or in centimeters of water. Tensiometers that utilize a mercury manometer are usually preferred as research tools because they afford great precision. Because of their simplicity, tensiometers equipped with Bourdon vacuum gages are better suited to practical use and to irrigation control.

After the cup is placed in the soil at the desired depth, the instrument must be filled with water. Water moves through the porous cup until the water in the cup and the water in the soil reach equilibrium. Any increase in tension that occurs as the soil dries causes the vacuum-gage reading, which can be read above ground, to increase. Conversely, an increase in soil-water content reduces tension and lowers the gage reading. The tensiometer continues to record fluctuations in soil-water content unless the tension exceeds 0.85 atmosphere, at which point air enters the system and the instrument ceases to function. After an irrigation or rain, the instrument must again be filled with water before it can operate.

Some experience is required to use a tensiometer. If air enters the unit through any leaks at the rubber connections, measurements are not reliable. Air leaks can result from faulty cups. They may occur also at the contact points of the setscrews used to secure the porous cup to the metal support. Some manufacturers provide a test pump that can be used to test the gage and to remove air from the instrument.

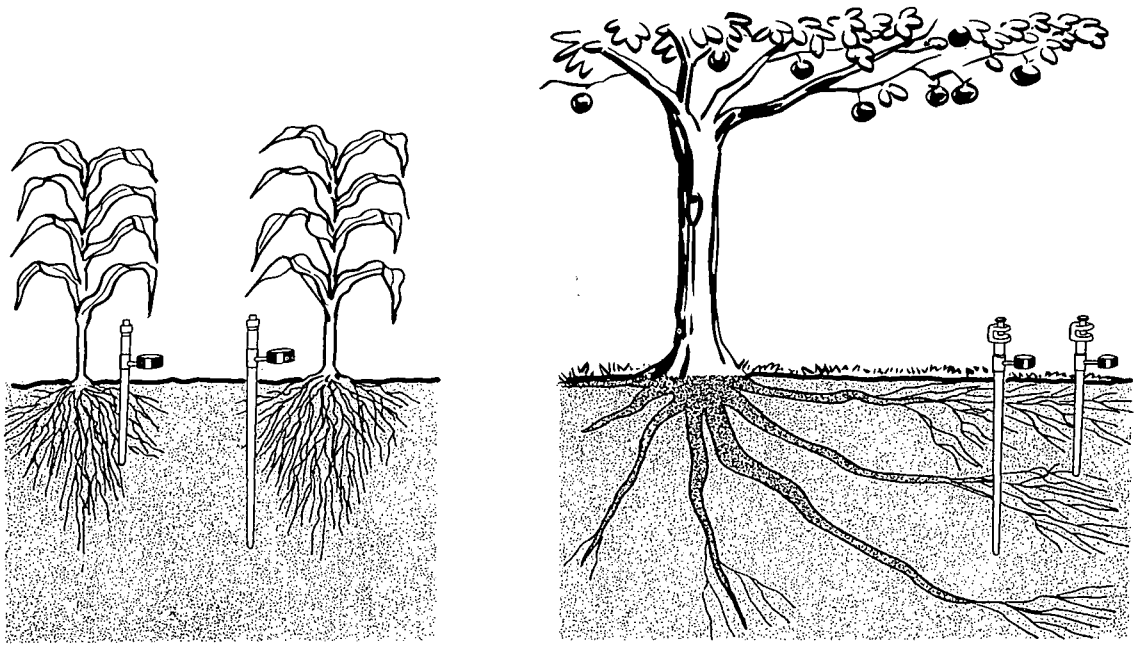


Figure 7-1 --Tensiometers used to measure soil moisture.

Tensiometer readings reflect soil-moisture tension only; that is, they indicate the relative wetness of the soil surrounding the porous tip. They do not provide direct information on the amount of water held in the soil. Tension measurements are useful in deciding when to irrigate, but they do not indicate how much water should be applied. A special moisture-characteristic curve for the particular soil is needed to convert moisture-tension measurements into available-moisture percentages. Typical curves for three sample soils are shown in figure 7-2.

Tensiometers do not satisfactorily measure the entire range of available moisture in all soil types. But they probably are the best field instruments to use to determine moisture conditions in the wet range. They are best suited to use in sandy soils since in these soils a large part of the moisture available to plants is held at a tension of less than 1 atmosphere. Tensiometers are less well suited to use in fine-textured soils in which only a small part of the available moisture is held at a tension of less than 1 atmosphere.

Electrical-Resistance Instruments. These instruments (fig. 7-3) use the principle that a change in moisture content produces a change in some electrical property of the soil or of an instrument in the soil. They consist of two electrodes permanently mounted in conductivity units, usually blocks of plaster of paris, nylon, fiber glass, gypsum, or combinations of these materials. Electrodes in the blocks are attached by wires to a resistance or conductance meter that measures changes in electrical resistance in the blocks. When the units are buried in the soil, they become almost a part of the soil and respond to changes in soil-moisture content. Since the amount of moisture in

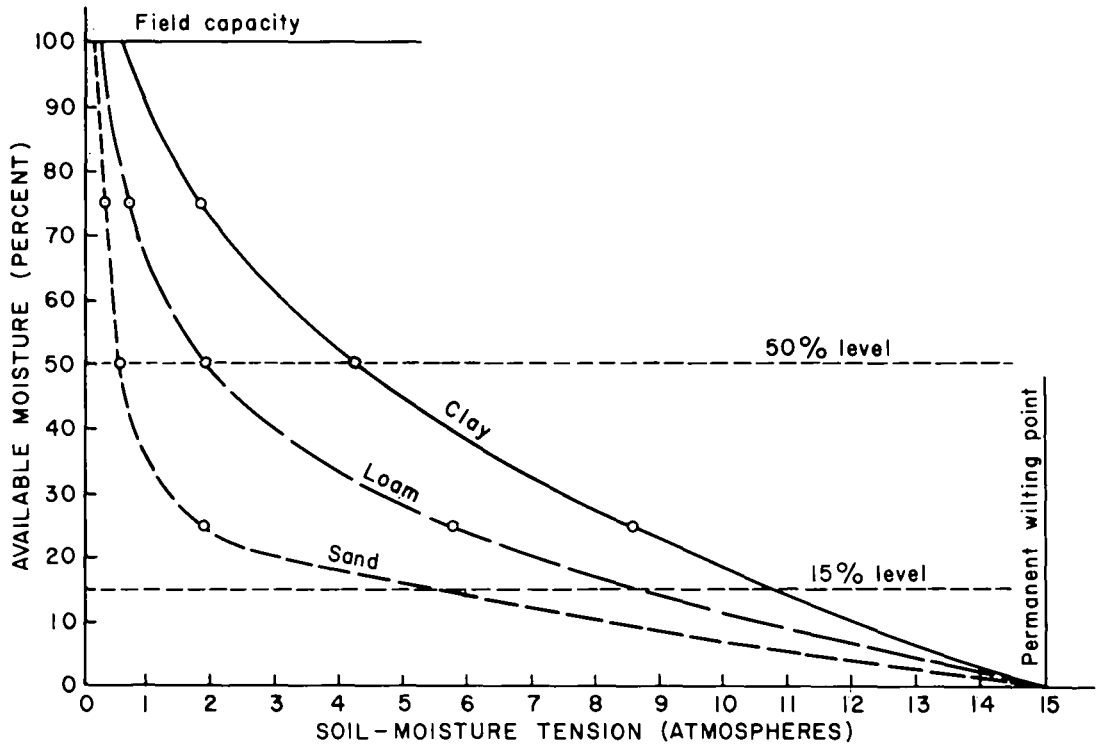


Figure 7-2 --Moisture-release curves for three soils. (From Thorne, M. D., and Raney, W. A. Soil Moisture Evaluation. U.S. Dept. Agr. ARS 41-6, 14 pp. 1956.)

the blocks determines electrical resistance, measurement of any change in resistance is an indirect measure of soil moisture if the block is calibrated for a particular soil.

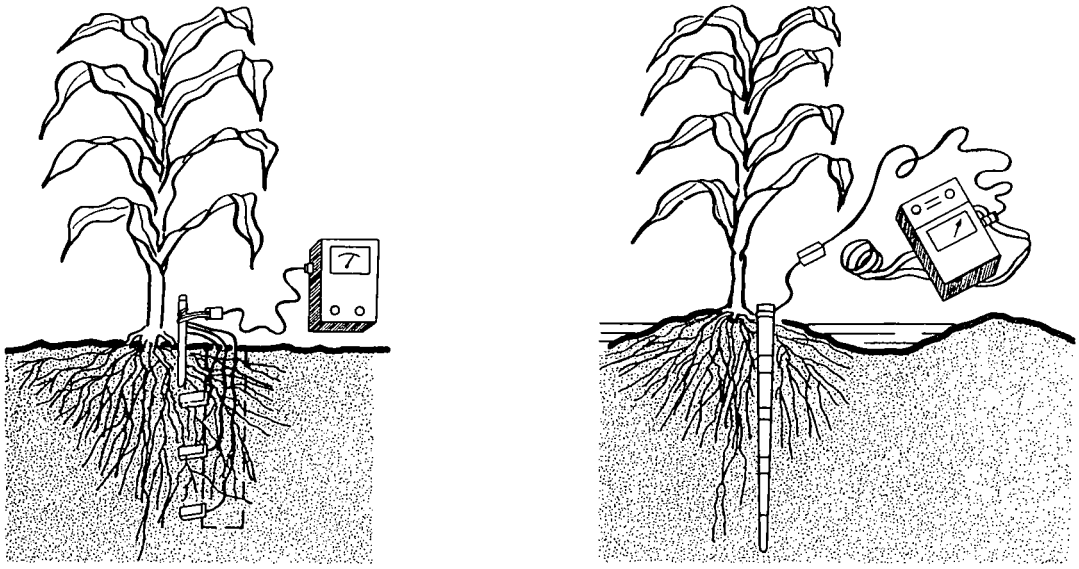


Figure 7-3 --Electrical-resistance soil-moisture meters.

Nylon and fiber-glass units are more sensitive in the higher ranges of soil moisture than plaster of paris blocks, but often their contact with soil that is alternately wet and dry is not very good. Nylon units are most sensitive at a tension of less than 2 atmospheres. Plaster of paris blocks function most effectively at a tension between 1 and 15 atmospheres, and fiber-glass units operate satisfactorily over the entire range of available moisture. A combination of fiber glass and plaster of paris provides sensitivity in both the wet and dry range and provides good contact between the soil and the unit.

Electrical-resistance instruments are sensitive to salts in the soil; fiber-glass units are more sensitive than plaster of paris. Their readings are also affected by concentrations of fertilizer. Where fertilizer is spread in bands, the unit should be placed well to one side of the bands. Temperature also affects readings in all units but much less than other sources of variation. In some units calibration drift has caused changes of as much as 1 atmosphere of tension in a single season. The magnitude of a change depends on the number of drying intervals and the number of days between each. Readings also vary with soil type. Since the same reading may indicate different amounts of available moisture for different soil textures, the instrument must be calibrated for the soil in which it is to be used.

If readings are to be representative of an area, the blocks must be properly installed. Individual blocks must be placed in a hole, which disturbs the soil. If the soil is not replaced in the hole at the same density and in the same way as in the rest of the profile, the root-development and moisture pattern may not be representative. A good method is to force the block into undisturbed soil along the sides of the hole dug for placement of the blocks (fig. 7-3). In one type, the

blocks are cast in a tapered stake. A tapered hole, the same size as the stake, is bored into the ground with a special auger. The stake is saturated with water and then pushed into the hole so that close contact is made between the stake and the soil.

Most of the commercial instruments give good indications of moisture content if they are used according to the manufacturer's instructions. For good results, however, the blocks need to be calibrated in the field for each job. Experience and careful interpretation of instrument readings are needed to get a good estimate of soil-moisture conditions.

Feel and Appearance Method

How soil samples taken in the field from appropriate locations and depths feel and look gives some indication of moisture content. A shovel can be used to get samples, but for some soils a soil auger or a sampling tube is better. The appearance and feel of a handful of soil that has been squeezed very firmly can be compared with descriptions in a guide of estimated available-moisture content for different soil textures and conditions. Table 7-5 is a guide that has been used for some time.

A slightly different and probably simpler guide was developed by John L. Merriam. In this guide (table 7-6) moisture deficiency can be read directly in inches per foot. The description at the top of each textural column is of the soil at field capacity. The description at the bottom of each column is of the soil at the wilting point. Descriptions of intermediate conditions of soil-moisture deficiency are opposite the corresponding numerical values of inches of water per foot of soil. Table 7-6 is for a specific group of soils, and it may not apply to many other groups. Descriptions for other soils may be somewhat different. Probably the best practice is to prepare a chart for a given area and for specific soils and then to furnish each irrigator with a chart that describes only the soils to be irrigated on his farm. These special charts should be developed by using laboratory methods to determine the soil-moisture deficiency that corresponds to each feel and appearance condition.

Although gaging moisture conditions by feel and appearance is not the most accurate method, with experience and judgement the irrigator should be able to estimate the moisture level within 10 to 15 percent. This method is one of the cheapest, but it requires a lot of work to get soil samples.

Table 7-5--Practical interpretation chart on soil moisture for various soil textures and conditions.

Available moisture in soil	Feel or appearance of soil			
	Coarse-textured soils	Moderately coarse textured soils	Medium-textured soils	Fine and very fine textured soils
0 percent--	Dry, loose, and single-grained; flows through fingers.	Dry and loose; flows through fingers.	Powdery dry; in some places slightly crusted but breaks down easily into powder.	Hard, baked, and cracked; has loose crumbs on surface in some places.
50 percent or less.	Appears to be dry; does not form a ball under pressure.[1]	Appears to be dry; does not form a ball under pressure.[1]	Somewhat crumbly but holds together under pressure.	Somewhat pliable; balls under pressure.[1]
50 to 75 percent.	Appears to be dry; does not form a ball under pressure.[1]	Balls under pressure but seldom holds together.	Forms a ball under pressure; somewhat plastic; slicks slightly under pressure.	Forms a ball; ribbons out between thumb and forefingers.
75 percent to field capacity.	Sticks together slightly; may form a very weak ball under pressure.	Forms weak ball that breaks easily; does not slick.	Forms ball; very pliable; slicks readily if relatively high in clay.	Ribbons out between fingers easily; has a slick feeling.
At field capacity (100 percent).	On squeezing, no free water appears on soil but wet outline of ball is left on hand.	Same as for coarse-textured soils at field capacity.	Same as for coarse-textured soils at field capacity.	Same as for coarse-textured soils at field capacity.
Above field capacity.	Free water appears when soil is bounced in hand.	Free water is released with kneading.	Free water can be squeezed out.	Puddles; free water forms on surface.

[1] Ball is formed by squeezing a handful of soil very firmly.

Table 7-6--Soil moisture and appearance relationship chart[1]

Moisture deficiency, in/ft	SOIL TEXTURE CLASSIFICATION			
	Coarse (loamy sand)	Light (sandy loam)	Medium (loam)	Fine (clay loam)
	(field capacity)	(field capacity)	(field capacity)	(field capacity)
0.0	Leaves wet outline on hand when squeezed.	Appears very dark, leaves wet outline on hand; makes a short ribbon.	Appears very dark; leaves a wet outline on hand; will ribbon out about one inch.	Appears very dark; leaves slight moisture on hand when squeezed; will ribbon out about two inches.
0.2	Appears moist; makes a weak ball.	Quite dark color; makes a hard ball.	Dark color; forms a plastic ball; slicks when rubbed.	Dark color; will slick and ribbon easily.
0.4	Appears slightly moist, sticks together slightly.	Fairly dark color, makes a good ball.	Quite dark, forms a hard ball.	Quite dark, will make a thick ribbon; may slick when rubbed.
0.6	Very dry, loose; flows through fingers. (wilting point)	Slightly dark color, makes a weak ball.	Fairly dark, forms a good ball.	Fairly dark, makes a good ball.
0.8		Lightly colored by moisture, will not ball.	Slightly dark, forms a weak ball.	Will ball, small clods will flatten out rather than crumble.
1.0		Very slight color due to moisture.(wilting point)	Lightly colored; small clods crumble fairly easily.	Slightly dark, clods crumble.
1.2				
1.4				
1.6				

Table 7-6--Soil moisture and appearance relationship chart[1] (cont'd)

Moisture deficiency, in/ft	SOIL TEXTURE CLASSIFICATION			
	Coarse (loamy sand)	Light (sandy loam)	Medium (loam)	Fine (clay loam)
	(field capacity)	(field capacity)	(field capacity)	(field capacity)
1.8			Slight color due to moisture, small clods are hard. (wilting point)	
2.0				Some darkness due to unavailable moisture, clods are hard, cracked (wilting point)

This chart indicates approximate relationship between field capacity and wilting point. For more accurate information, the soil must be checked by drying samples of it. The descriptions at the top of each textural column correspond to the condition of zero soil-moisture deficiency, ie., field capacity. Those descriptions at the bottom of a column describe a soil having the maximum deficiency, i.e., at wilting point. The soil-moisture deficiency at this condition is numerically equal to the available moisture range of the soil. Intermediate soil-moisture deficiency descriptions occur opposite corresponding numerical values of inches of water per foot of depth at which the soil is deficient. This chart describes a specific group of soils and though it has been found to have general application, it may not apply to many other groups. Where this is the case, new descriptions will need to be prepared corresponding to particular soil-moisture deficiency, feel, and appearance relationships.

[1] From Merriam, J. L. Field Method of Approximating Soil Moisture for Irrigation. Amer. Soc. Agr. Engin. Trans. 3(1): 31-32. 1960.

APPENDIX

Item

List of Crop Growth Stage Coefficient Curves

Crop Growth Stage Coefficient Curves

Agricultural Extension Bulletin M-158 (Irrigation Wells)

Agricultural Extension Bulletin M-152 (Nitrogen Fertilizer Injection)

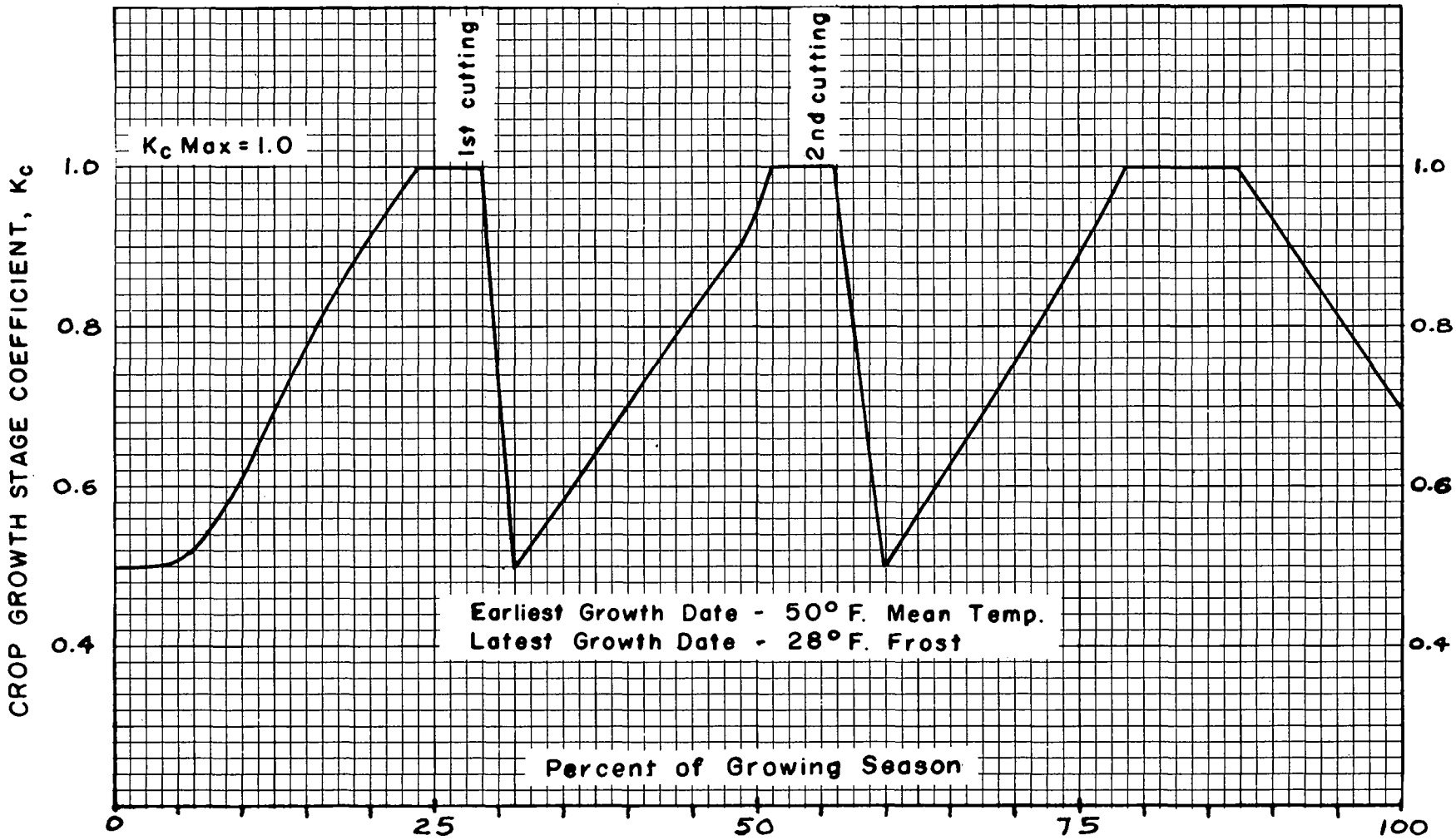
Agricultural Extension Bulletin M-150 (Safety Controls for Irrigation Power Units)

Circular AE-88, Extension Service, North Dakota State University (Irrigation Power Unit Selection)

Circular AE-89, Extension Service, North Dakota State University (Irrigation Pumps)

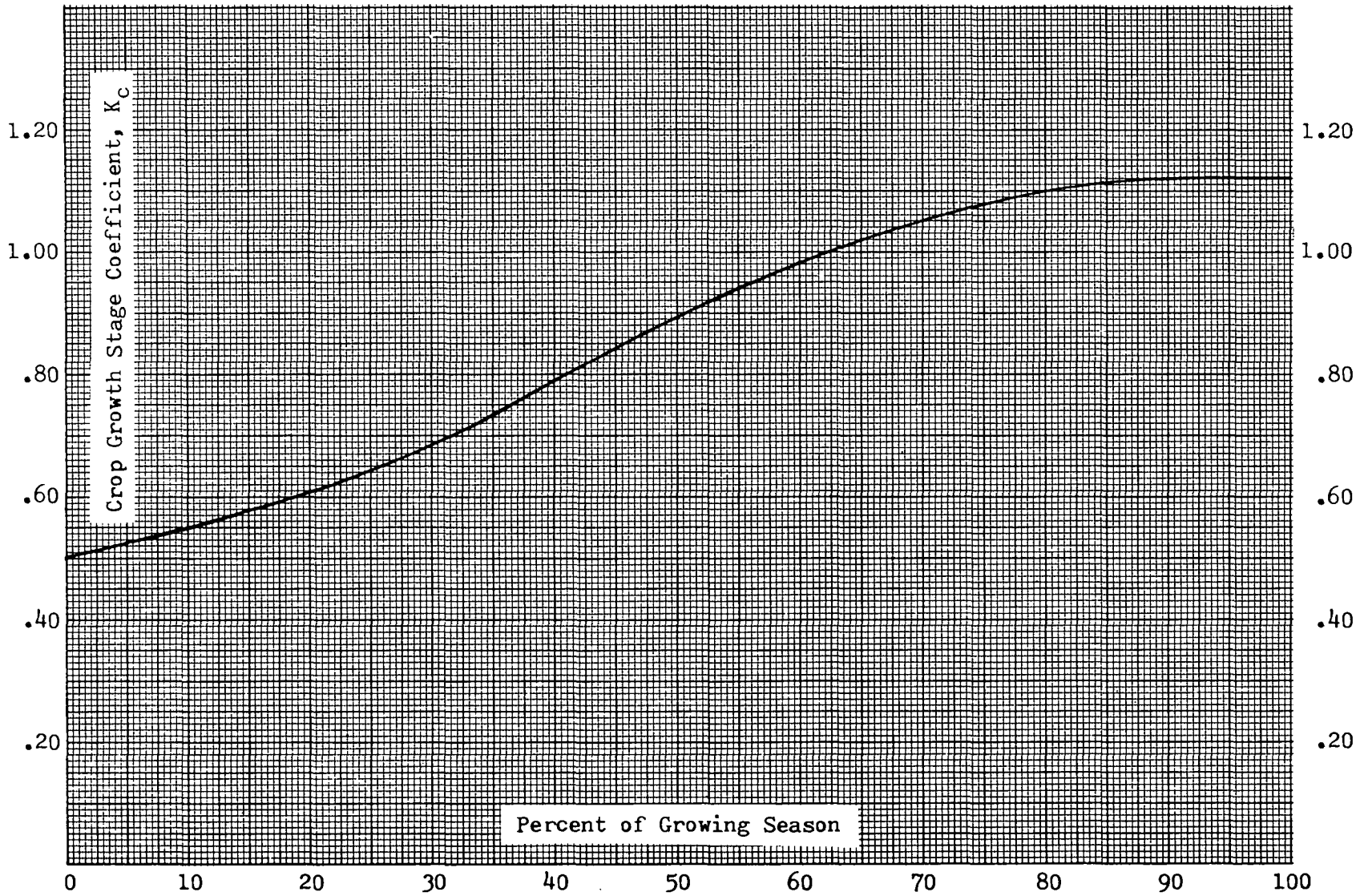
List of Crop Growth Stage Coefficient Curves

Crop	Curve No.
Alfalfa	2
Beans, dry	8
Beans, snap	3
Beets, sugar	9
Corn, grain	1
Corn, silage	11
Corn, sweet	5
Grain, spring	13
Pasture grasses	17
Peas	6
Potatoes, Irish	18
Sorghum, grain	19
Soybeans	20
Tomatoes	21
Vegetables, small	22



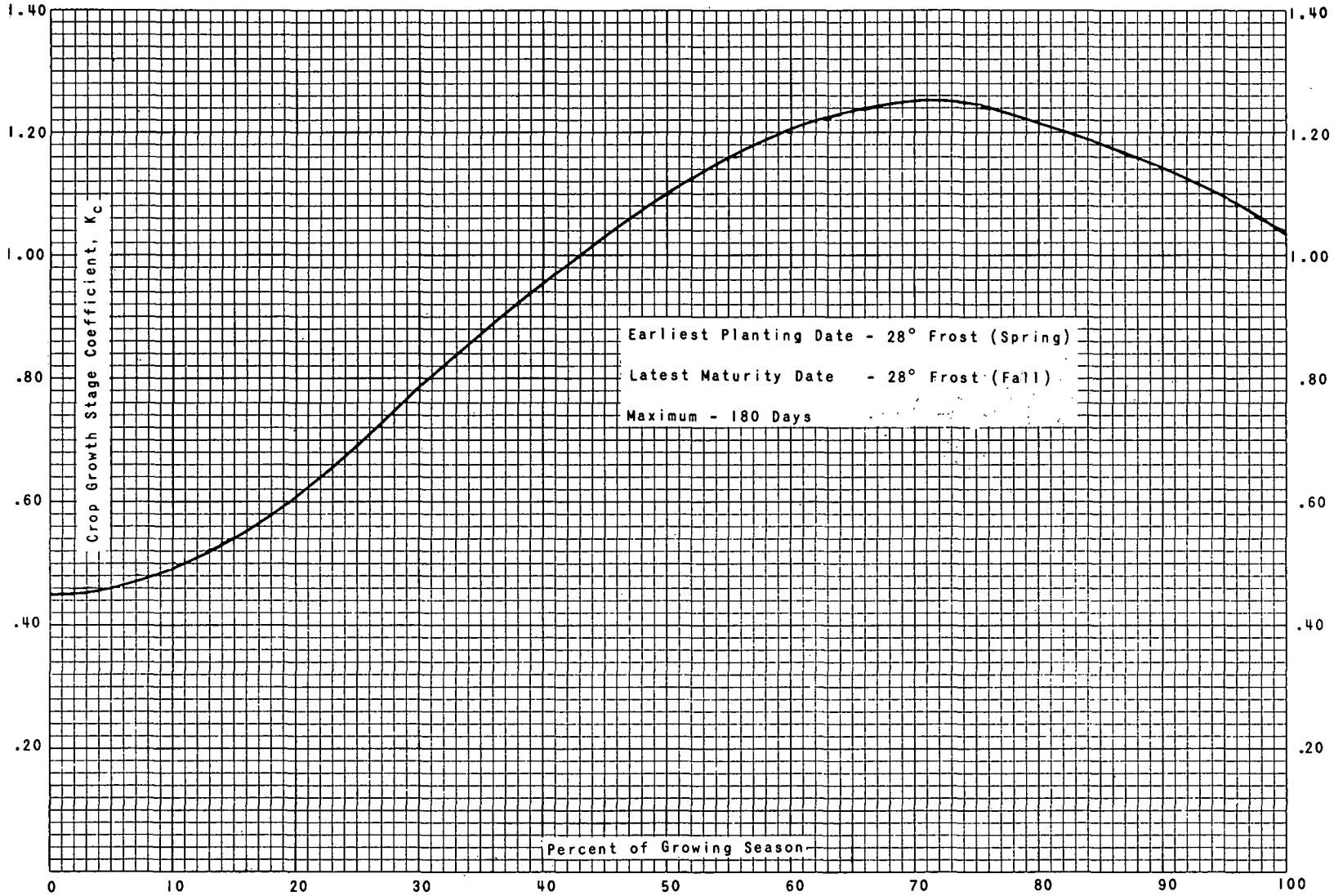
CROP GROWTH STAGE COEFFICIENT FOR ALFALFA

CURVE NO. 2



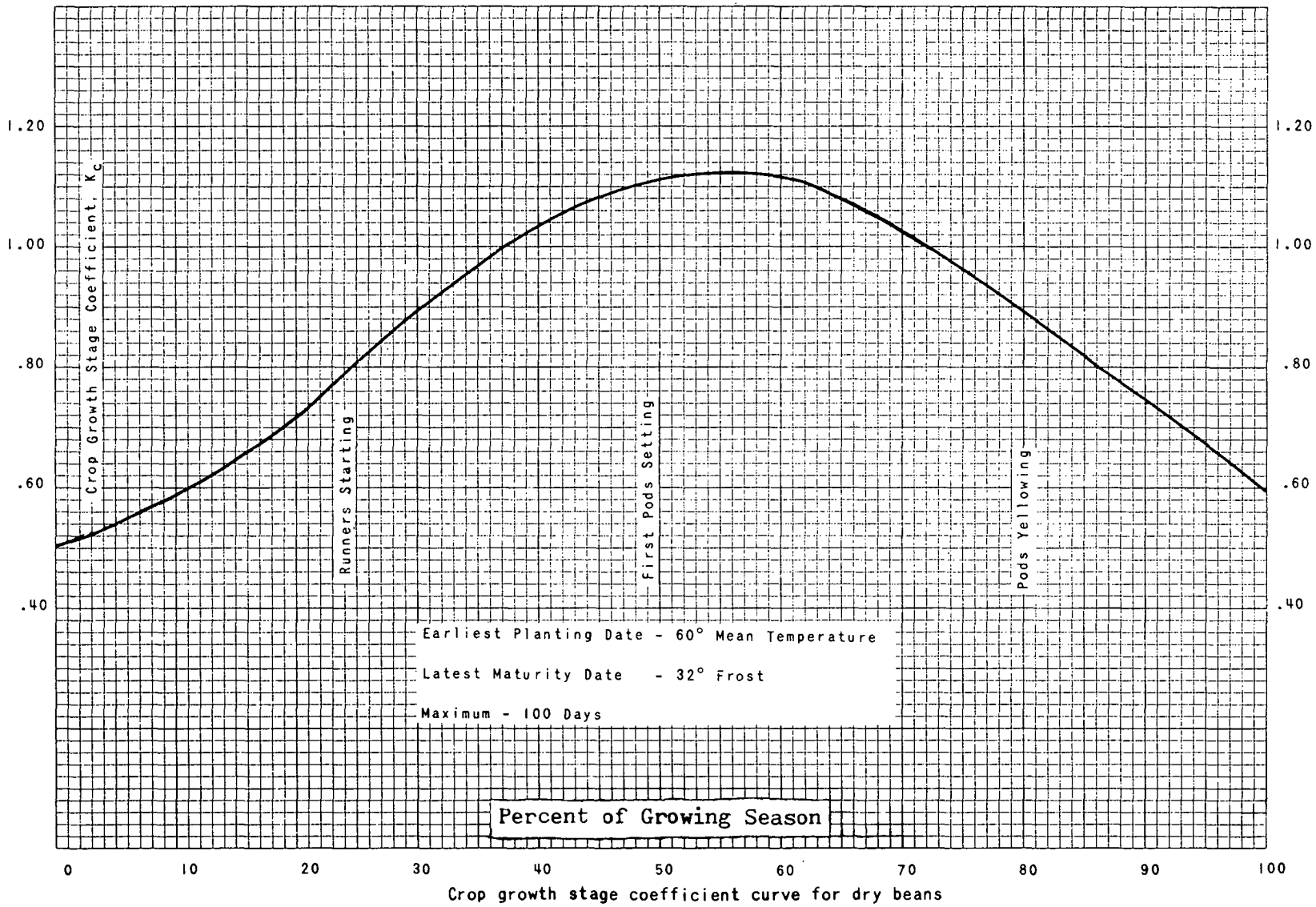
Crop growth stage coefficient curve for snap beans

Curve No. 3



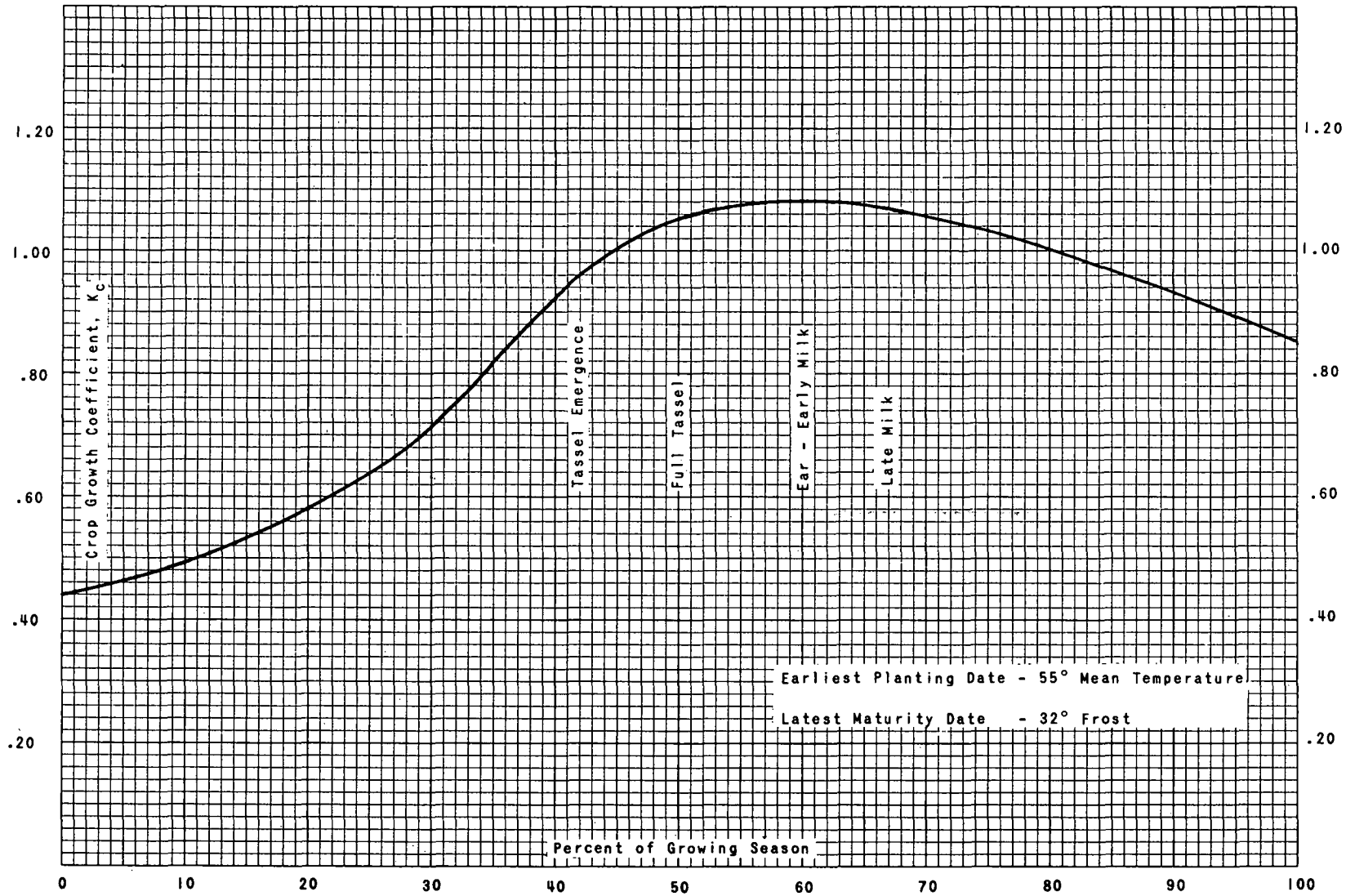
Crop growth stage coefficient curve for sugar beets

Curve No. 9



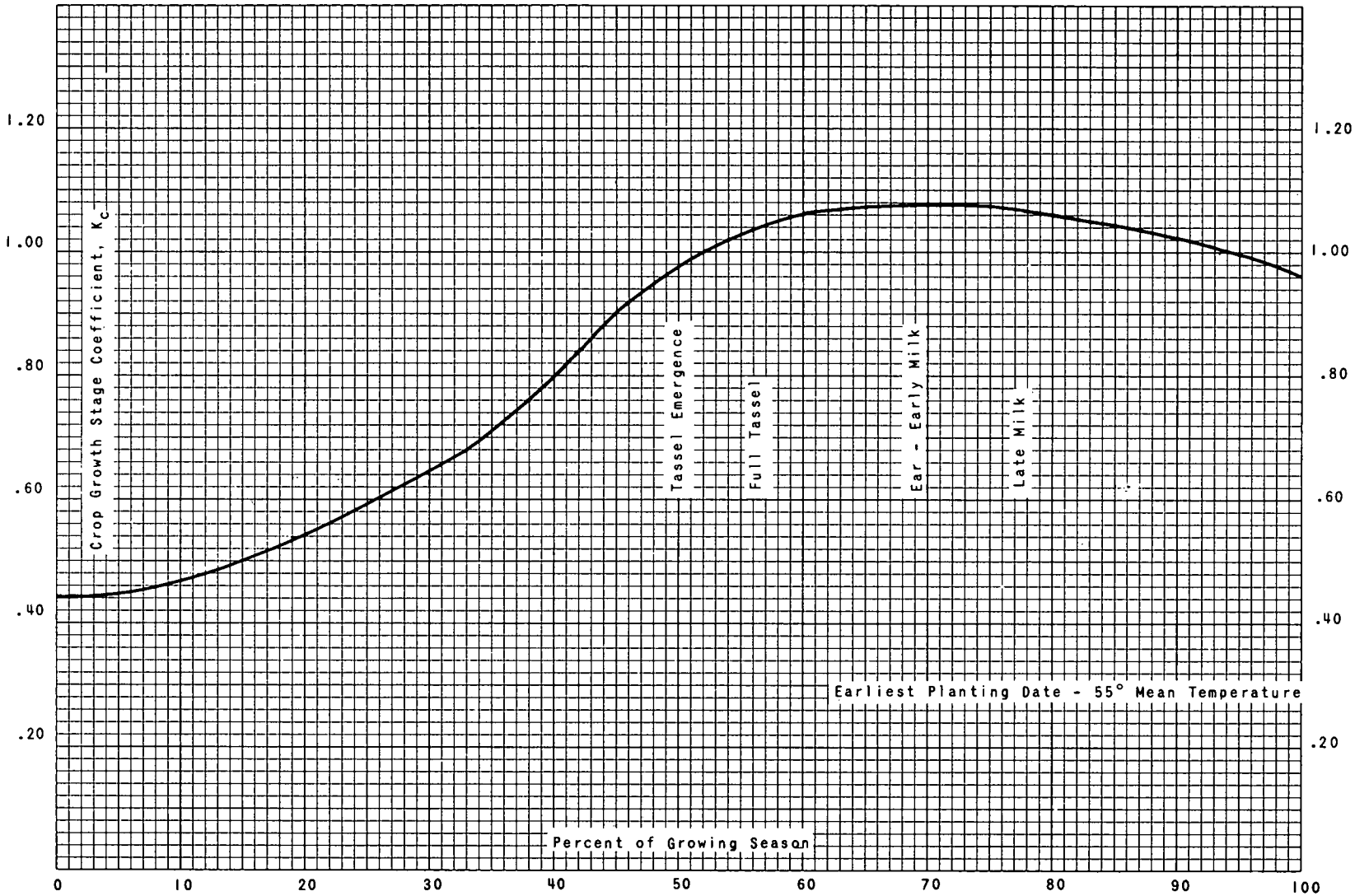
Crop growth stage coefficient curve for dry beans

Curve No. 8



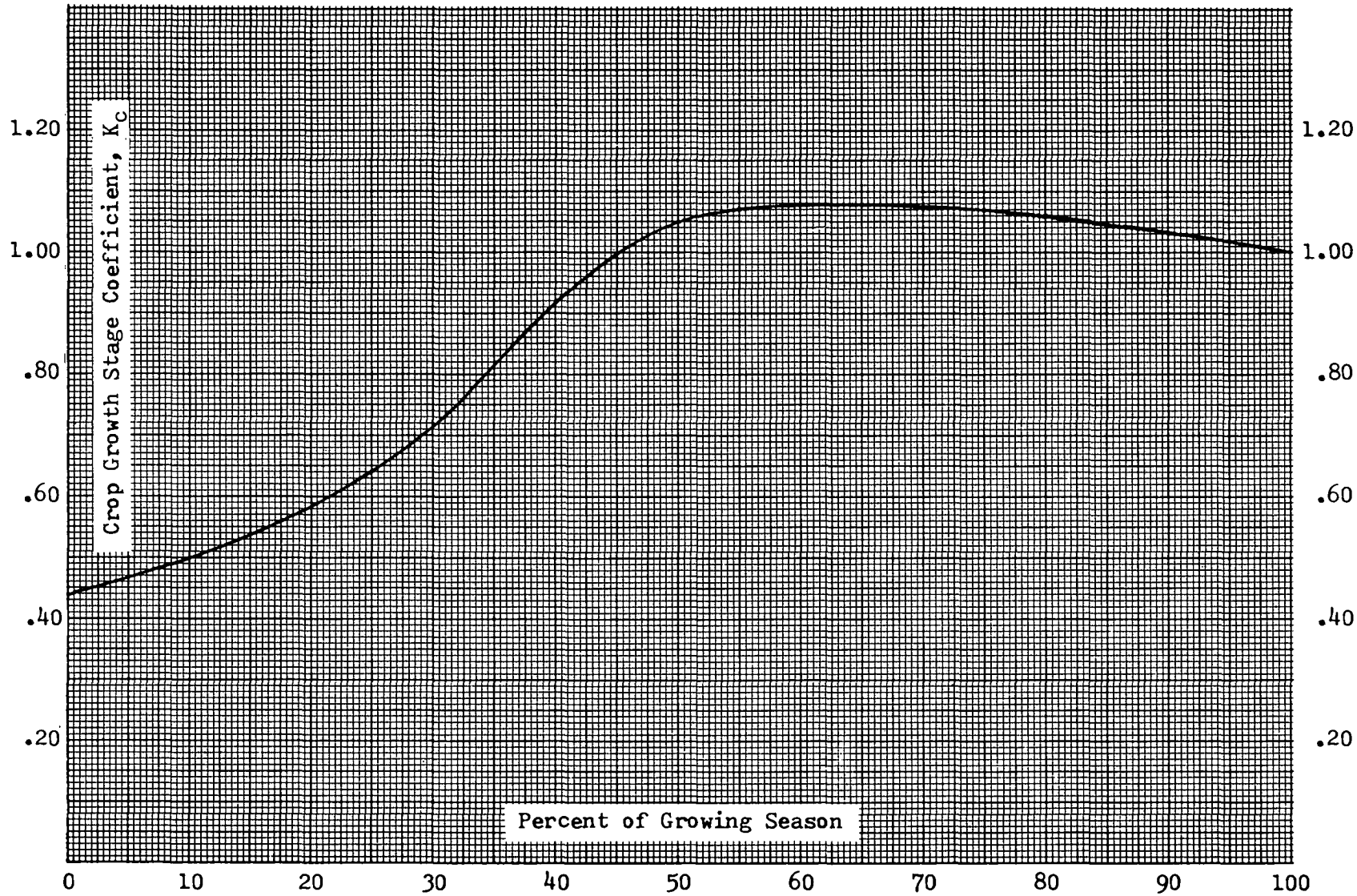
Crop growth stage coefficient curve for corn (grain)

Curve No. 1



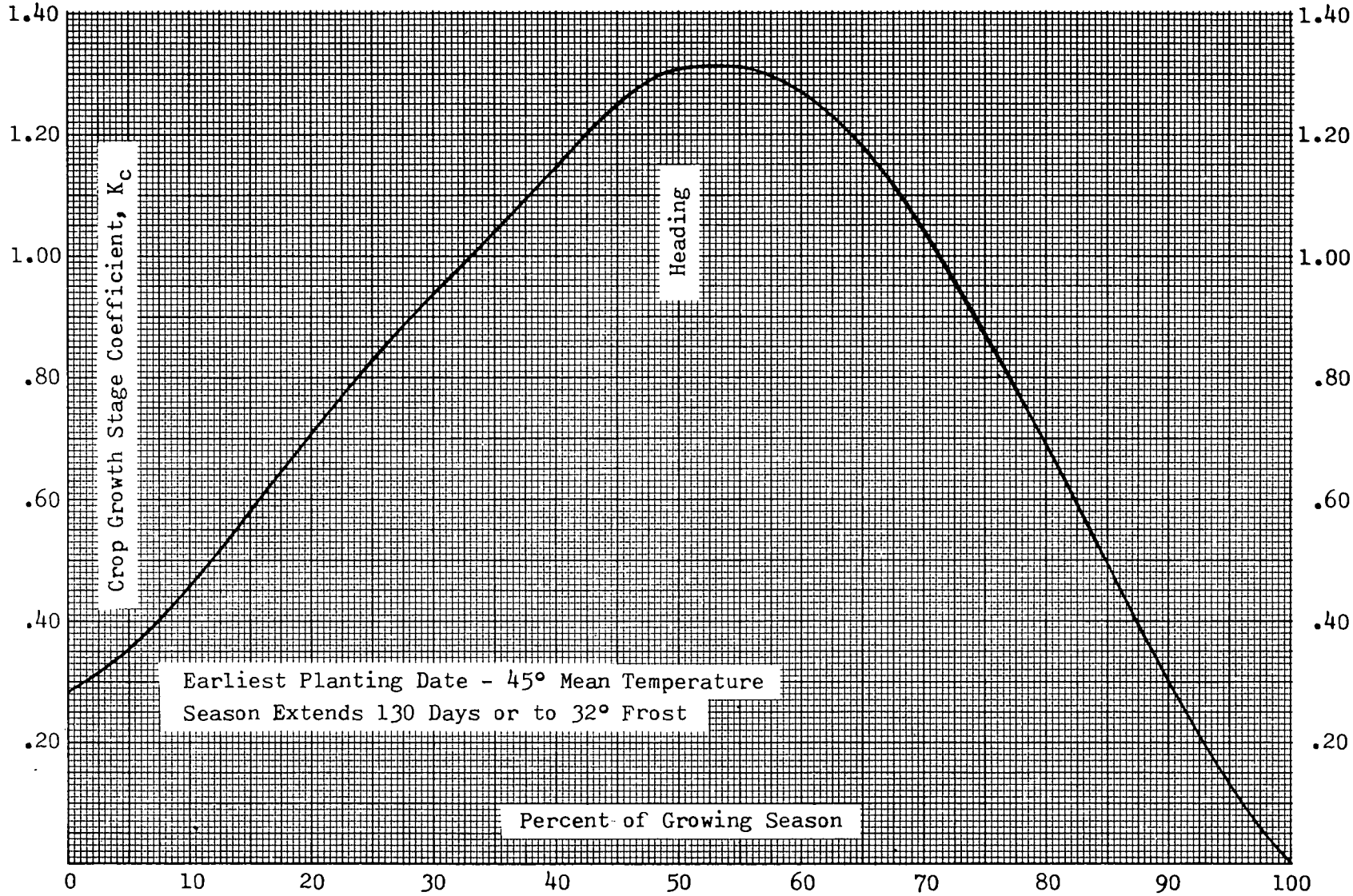
Crop growth stage coefficient curve for corn (silage)

Curve No. 11



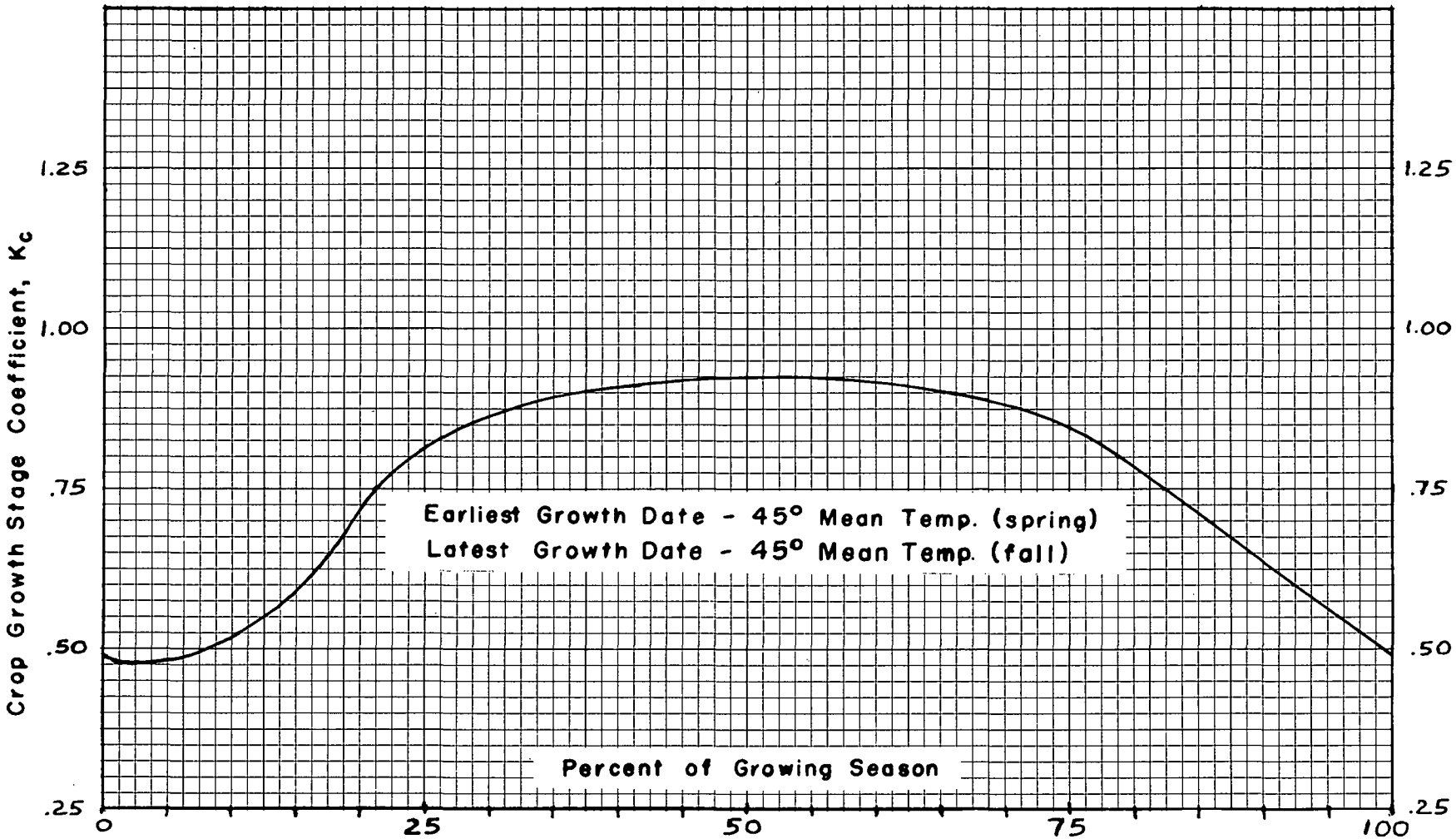
Crop growth stage coefficient curve for sweet corn

Curve No. 5



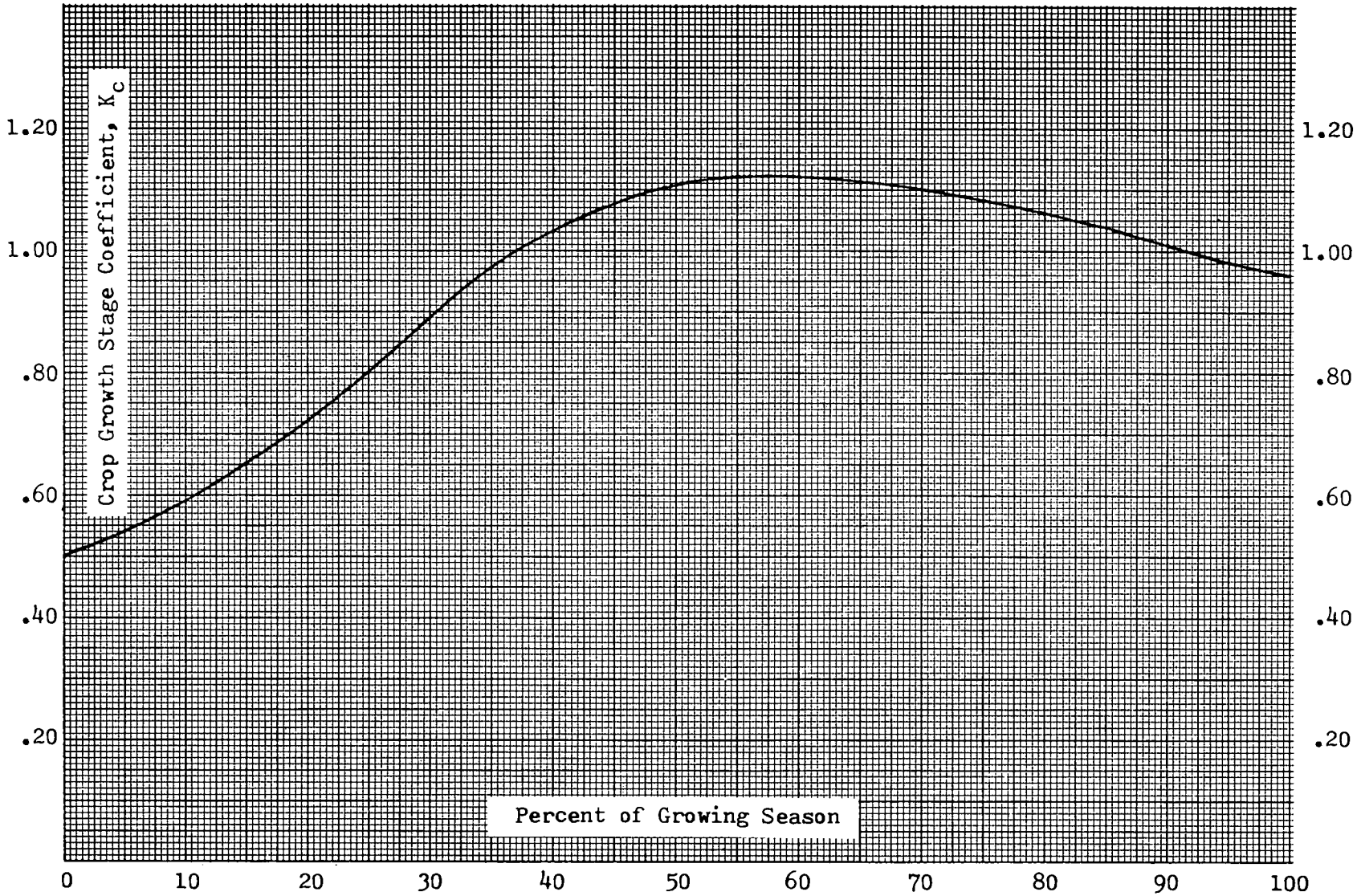
Crop growth stage coefficient curve for spring grain

Curve No. 13



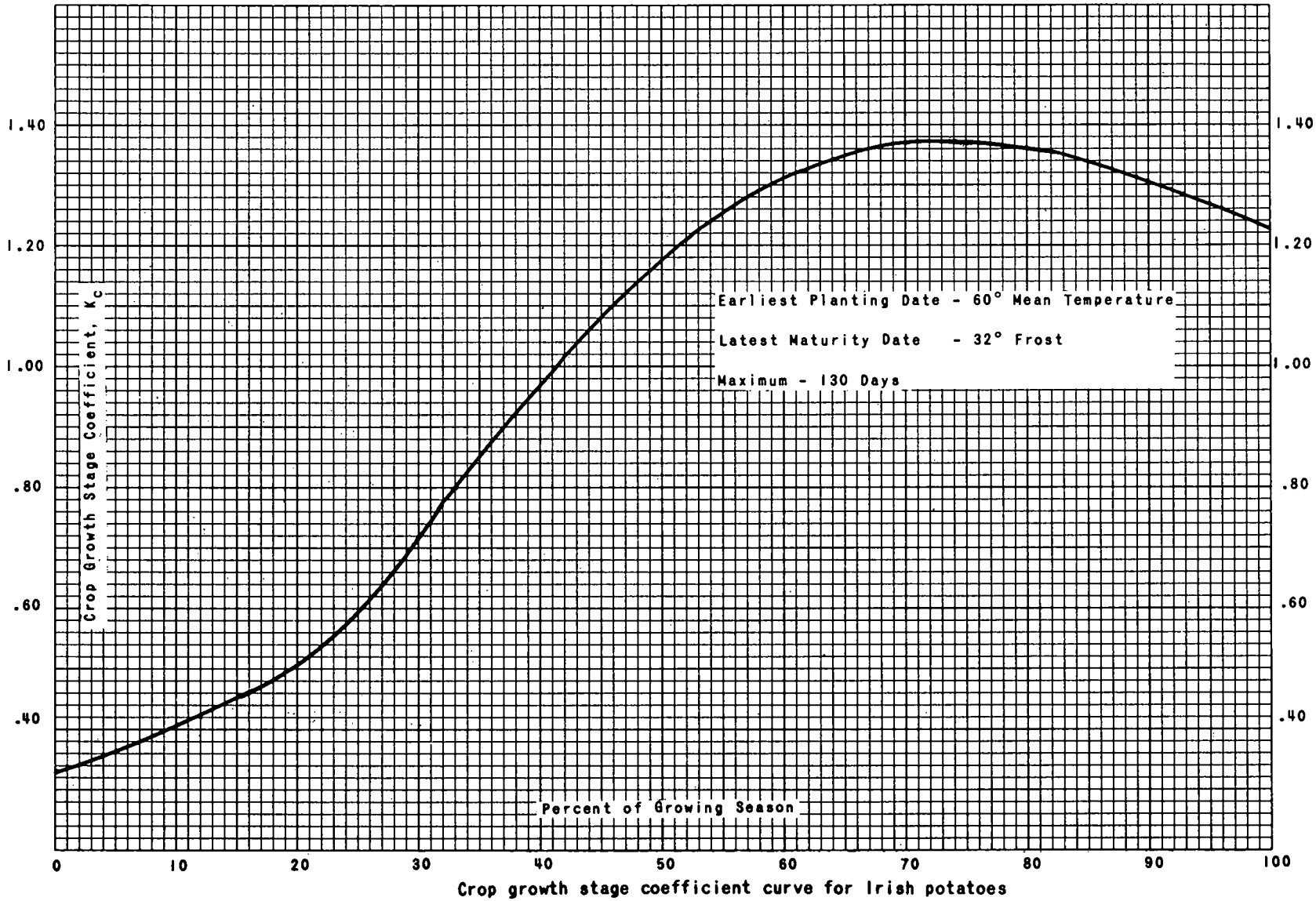
CROP GROWTH STAGE COEFFICIENT FOR PASTURE GRASSES

CURVE NO. 17



Crop growth stage coefficient curve for peas

Curve No. 6



Crop growth stage coefficient curve for Irish potatoes

Curve No. 18

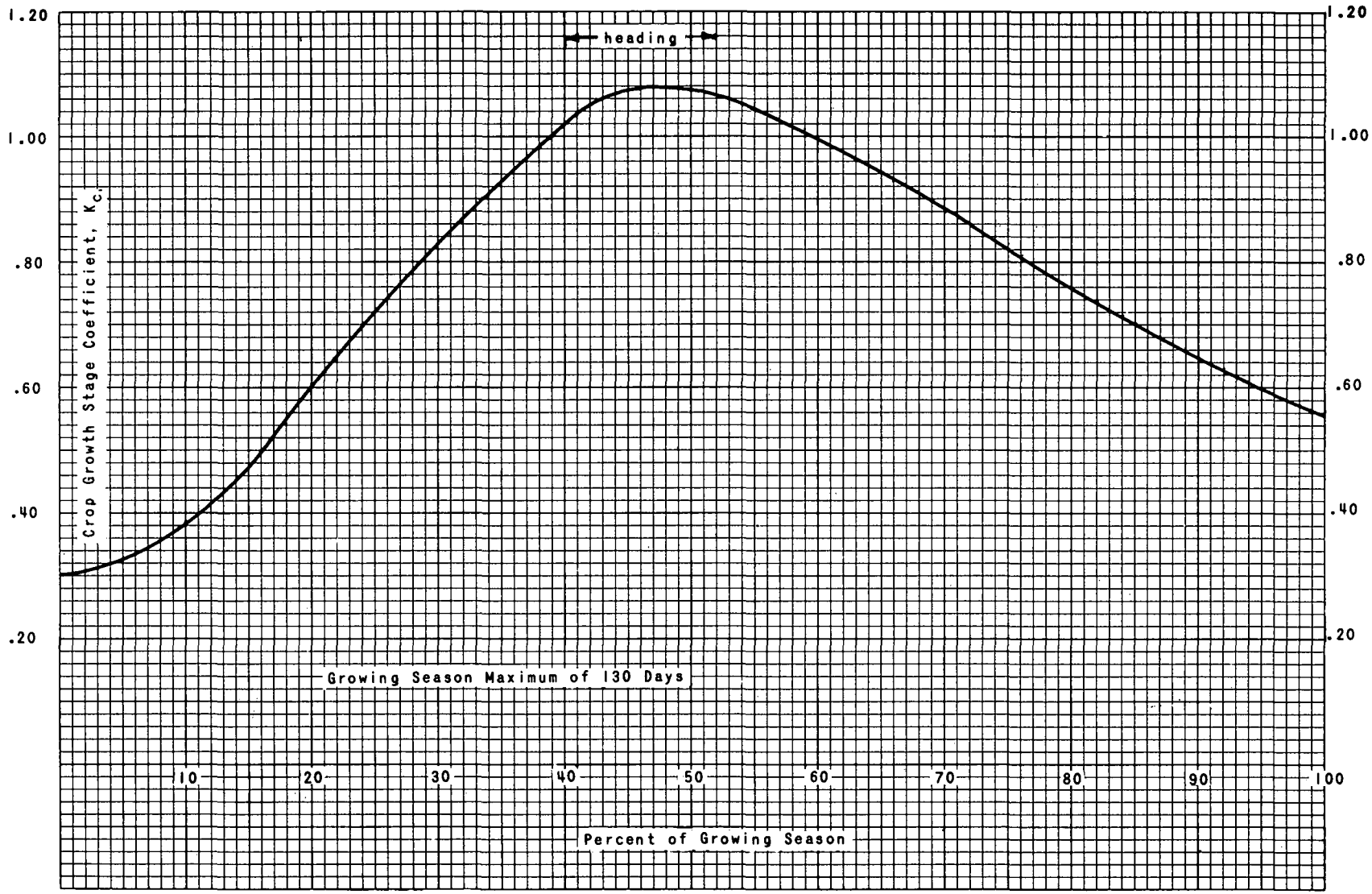
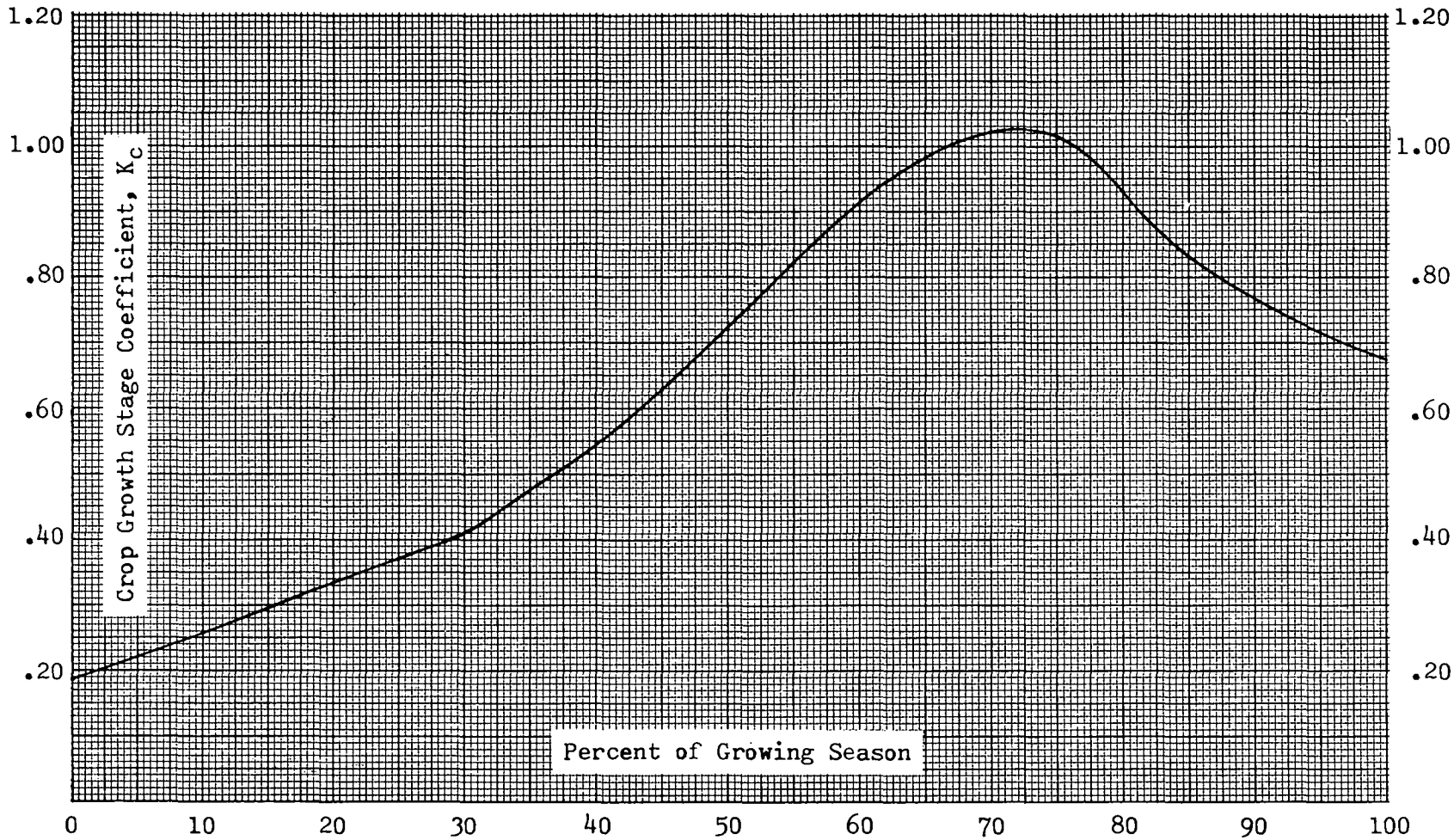


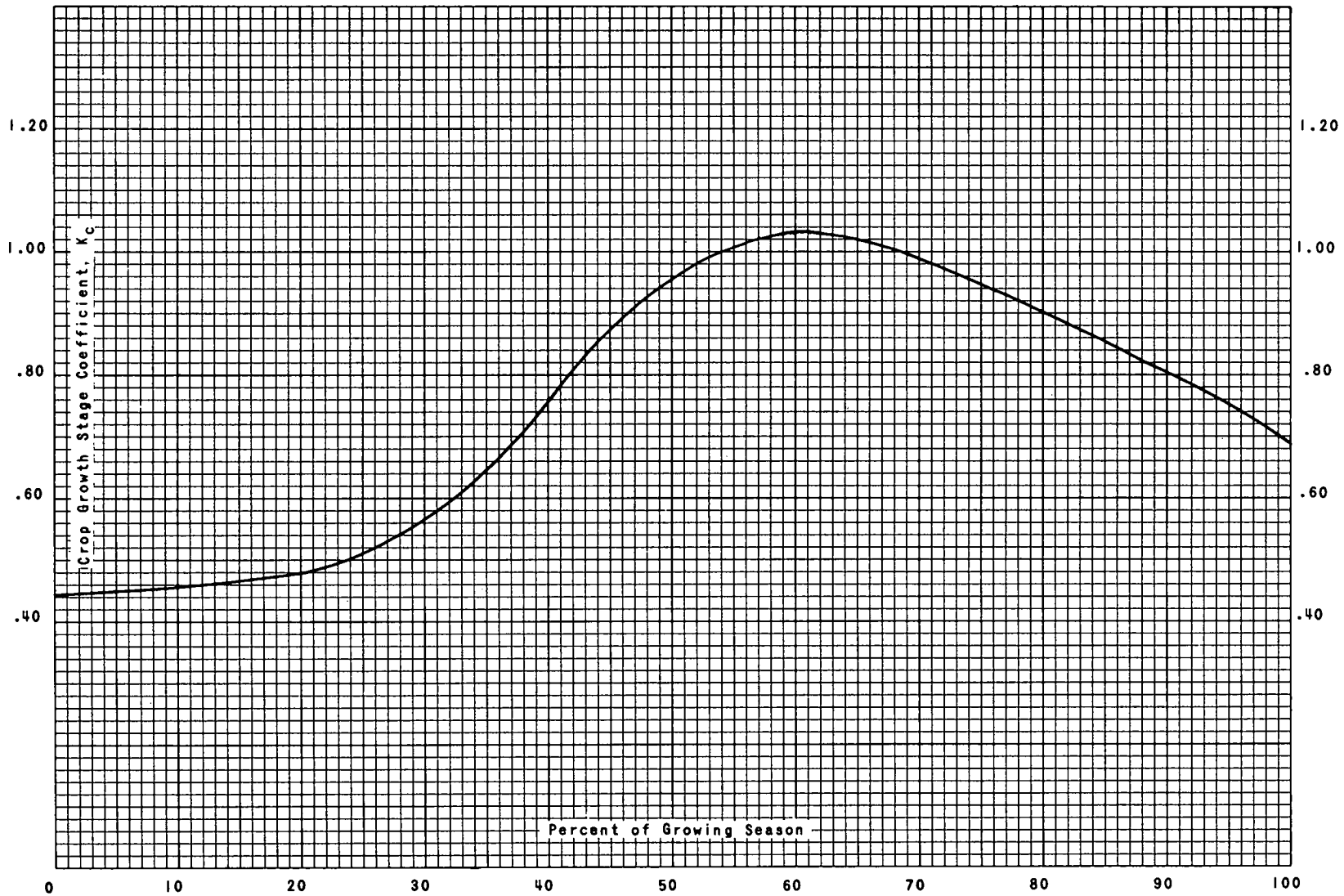
Figure 19 - Crop growth stage coefficient curve for grain sorghum

Curve No. 19



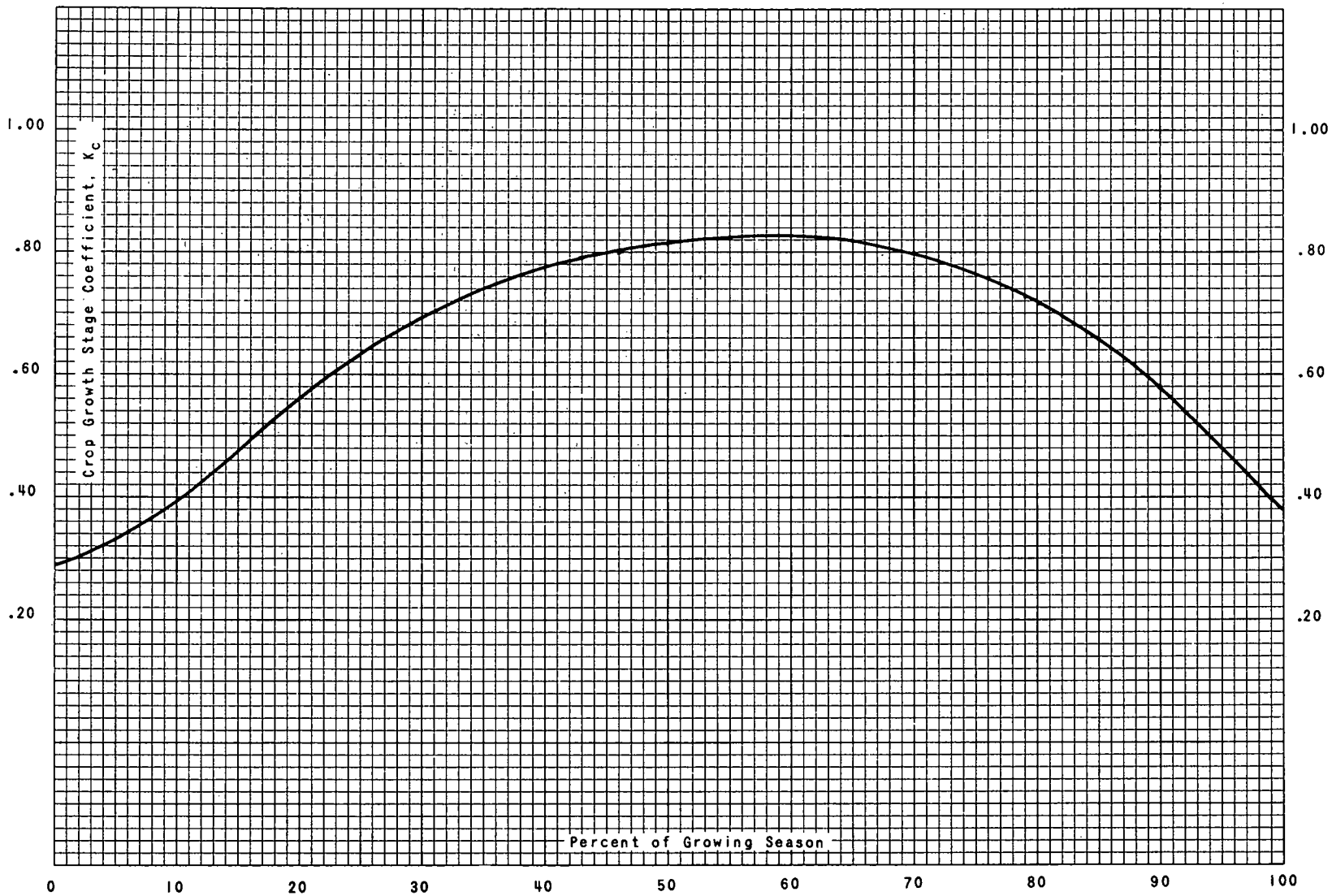
Crop growth stage coefficient curve for soybeans

Curve No. 20



Crop growth stage coefficient curve for tomatoes

Curve No. 21



Crop growth stage coefficient curve for small vegetables

Curve No. 22

AGRICULTURAL EXTENSION SERVICE • UNIVERSITY OF MINNESOTA

M-158
1972

Irrigation Wells

Roger E. Machmeier, extension agricultural engineer

A satisfactory irrigation well may represent an investment of several thousand dollars and should be investigated, constructed, and developed to insure a dependable source of water for many years.

Well design, construction, development, and testing are the responsibilities of the driller, but the purchaser should also be aware of good well construction practices.

Aquifers

An *aquifer* is a water-saturated, subsurface layer that will yield water to wells or springs fast enough to serve as a water supply. *Water bearing formation* and *ground water reservoir* are other terms for aquifer.

To qualify as an irrigation aquifer, a geologic formation must contain pores or open spaces which are filled with water and are large enough to allow the water to move fast enough to supply an irrigation well. A saturated clay layer, even though the pores are filled with water, will not yield water rapidly to wells so it is not considered an aquifer. A saturated sand formation is an aquifer since water will move through it to a well or spring.

Two types of aquifers are present in Minnesota—water table and artesian. A water table aquifer is a continuous water-bearing formation in which the level of the water in an open hole in the formation and the water table are the same (figure 1).

An artesian aquifer is a water bearing formation in which the water level in an open hole rises above the top of the formation (figure 2). It is not required that water flow out the top of the well for the formation to be classified as an artesian aquifer.

Sand and gravel laid down by glaciers are called *unconsolidated* formations. The water bearing capabilities of glacial deposits vary considerably with the type of deposited material and depth of water bearing formation.

Rock layers which will yield supplies of water are called *consolidated* formations. The most common consolidated aquifer is sandstone. Large yielding wells can often be obtained by locating saturated crevices in limestone. In consolidated formations, type of formation and thickness of saturated layer usually determines well yield.

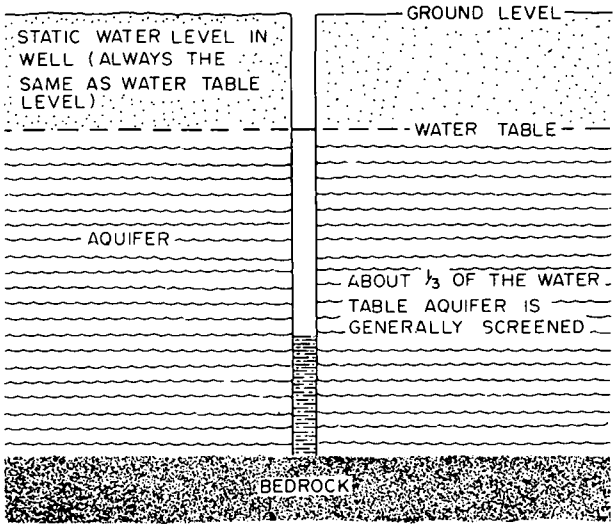


Figure 1. Water table aquifer

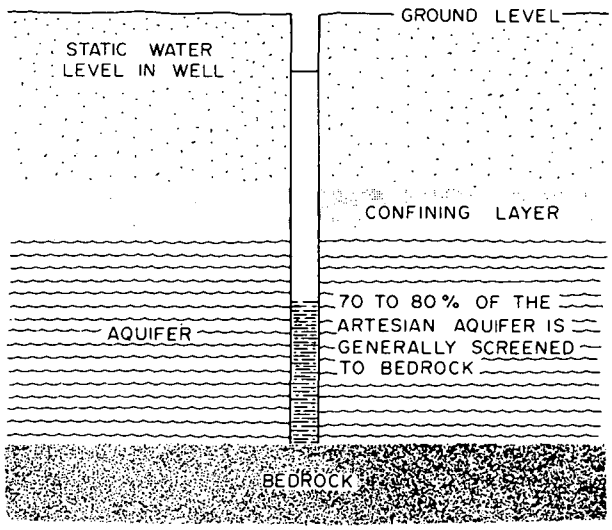


Figure 2. Artesian aquifer

Issued in furtherance of cooperative extension work in agriculture and home economics, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Roland H. Abraham, Director of Agricultural Extension Service, University of Minnesota, St. Paul, Minnesota 55101.

5M—2-72

Obtain A Water Use Permit

A permit must be obtained from the Department of Natural Resources before any state waters can be withdrawn and used for irrigation. Write to the Division of Waters, Soils, and Minerals of the Department of Natural Resources, Minnesota Centennial Building, St. Paul, Minnesota 55101, for application forms.

Hire A Professional Well Driller

Drilling an irrigation well is not a job for amateurs. Only a professional irrigation well contractor is thoroughly familiar with all the methods and equipment needed to bring in a good supply of ground water. Drilling techniques differ with the area and type of well desired. A great deal of know-how is involved in properly constructing and developing a well. The irrigation well contractor must be a man of many talents and is, in a sense, a water specialist, engineer, and craftsman. His business success and reputation are built on doing a good job for each customer and the new customer must rely on this reputation for a reliable job.

A good irrigation well contractor enjoys a sound retutation and is accustomed to working under terms of a written contract. His equipment is in good operating condition. He figures the job step-by-step, includes a breakdown of unit prices, and gives his customer a specific per foot drilling price. When the job is completed, he provides a record of layers penetrated by the well and a statement of work performed and materials used.

(Action of the 1971 Minnesota State Legislature require licensing of *all* well drilling contractors.)

Contact more than one driller before employing one. A drilling contractor whose price is much below the average should be thoroughly investigated. There are many means of cheapening well construction that may not be detected until too late. The slight additional cost of contracting with a reputable driller who knows your area can pay off in future years.

Write A Contract

It is good business to have a written contract. For both parties, a written agreement is valuable protection and prevents misunderstanding.

Since the location, design, construction, and development of the irrigation well depend on results of test drilling, the irrigation well contract should not be written until information has been collected and analyzed from the test drilling. It may be desirable to have separate contracts for test drilling and for the irigation well.

Sample contracts are shown on pages 10-12. Portions of the suggested contracts may be deleted or changed according to local conditions. Consult an attorney who will draw up a legal contract.

Drill Test Holes

A test hole should be the first step in irrigation well planning. It is a drilled hole, usually at least 4 inches in diameter, that may or may not be cased. It has the following purposes: to locate a water-bearing formation; to determine the quantity of water that can be expected from a well in that location; and to determine the quality of the water in the formation at that location.

Considerably different aquifers are often present under a section or even a quarter-section of land. Continue to have test holes drilled even if the first hole does not indicate an adequate irrigation water supply. Several test holes are usually necessary to verify that adequate water is not available for irrigation purposes.

In areas where consolidated (rock) formations already provide adequate water supplies, drilling a test hole usually is not necessary. Rely on information from nearly wells and the driller's experience.

In unconsolidated (sand and gravel) formations, representative samples of the material should be collected every 5 feet during test hole drilling. Running the sample through fine screens or sieves will provide information for selecting the well screen and will indicate whether a gravel pack should be used. This is called a sieve analysis. A prediction of expected well capacity can also be made.

Water Quality

Water quality may affect selection of screen material, screen design, and casing material. Carbonates in the water tend to deposit in screen openings. If the entrance velocity of the water is too fast, the rate of carbonate deposition on the screen is greatly increased. A screen with a large amount of open area and the ability to withstand acid treatment is necessary if the water has incrusting tendencies.

Water may also have corrosive tendencies and the screen and casing material may need to be selected to prevent this. Well screen manufacturers often have laboratory facilities to test water for either incrusting or corrosive tendencies. Private laboratories also can test water quality but may not analyze the results with respect to corrosive or incrusting tendencies.

In western and northwestern Minnesota, check water for the presence of salts and boron, which may change soil structure or be toxic to crops. For a more complete discussion of water quality, refer to *The Quality of Minnesota Waters for Irrigation*, Technical Bulletin 239, University of Minnesota Agricultural Experiment Station by E. R. Allred and R. E. Machmeier. Minnesota waters generally are suitable for irrigation.

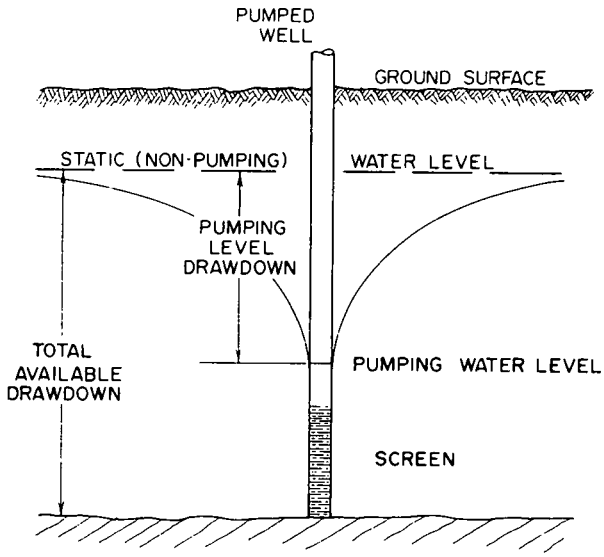


Figure 3. Well water levels and drawdown

Drawdown

Drawdown in a well is the difference in height between the pumping water level and the static (non-pumping) water level. Total available drawdown is the difference in height between the static water level and the bottom of the well (figure 3).

Pumping the water level below the top of the screen can have many detrimental effects on a well. Regardless of the aquifer type—artesian or water table—the drawdown should not drop below the top of the screen. The actual available drawdown for prolonged pumping is less than the total available drawdown.

Well Depth

The expected depth of the well is usually determined by information from the test hole and nearby wells in the same aquifer.

Generally a well is completed to the bottom of the aquifer. This is desirable because a higher water yield will be obtained due to more of the aquifer being penetrated and more drawdown being available.

Casing and Screen Diameter

The diameter of the well casing is determined by expected yield and pump size. Casing diameter should be two sizes larger than the bowl size of the pump (table 1). Ease of construction and relative casing cost may make a larger diameter desirable. It should be emphasized that the screen diameter and the well casing diameter need not be the same. Better and less expensive construction often results when the sizes are different.

Table 1. Recommended well diameters*

Anticipated well yield (gpm)	Nominal size of pump bowls (inches)	Optimum size of well casing (inches)	Smallest size of well casing (inches)
Less than 100	4	6 ID[1]	5 ID
75 to 175	5	8 ID	6 ID
150 to 400	6	10 ID	8 ID
350 to 650	8	12 ID	10 ID
600 to 900	10	14 OD	12 ID
850 to 1,300	12	16 OD	14 OD
1,200 to 1,800	14	20 OD	16 OD
1,600 to 3,000	16	24 OD	20 OD

* Reference: Ground Water and Wells, 1966, Universal Oil Products—Johnson Division, St. Paul, Minnesota.
[1] ID = Inside Diameter.
[2] OD = Outside Diameter.

Doubling the well diameter does not double the gallon yield. For example, if a 6-inch well yields 100 gpm (gallons per minute) with a certain drawdown, a 12-inch well will yield 110 gpm with the same drawdown, an 18-inch well will yield 117 gpm, and a 48-inch well, 137 gpm.

Gravel Pack

A gravel-packed well is constructed so the aquifer immediately surrounding the screen is made more permeable by removing the natural formation material and replacing it with coarser material from another source. Gravel-packed construction is recommended where the natural formation consists of fine uniform sands and/or where the formation is extensively laminated (consists of alternating fine, medium, or coarse layers that are thin and difficult to locate precisely). These conditions frequently exist in glacial deposits and most of these irrigation wells have been of the gravel-pack type.

Gravel-pack construction is usually more expensive because of the larger hole size required and purchase and delivery of the specially graded gravel-pack material. Where irrigation wells are drilled with reverse rotary drilling equipment, the additional cost of an increase in hole diameter is very small. Often, the cost of the pack material is more than offset by the shortened development time.

The entire screen length should be centered in the hole, with spacers placed at vertical intervals of about 20 feet to insure the pack will surround the entire screen uniformly.

A gravel pack completely surrounds the well screen and is of a size to prevent the fine particles of the formation beyond the gravel pack from entering the well. The gravel pack is more permeable than the surrounding formation. This higher permeability immediately surrounding the screen allows larger screen openings

than would be used without gravel pack. Larger openings permit more water to enter the well through the screen, while staying below the recommended entrance velocity.

Use Proper Gravel Pack Material

A good gravel pack material is clean with well-rounded, smooth, uniform grains. It should prevent the formation material from entering the well. The gravel size for the pack should be determined for each well. The gravel pack should be designed by the well screen manufacturer using information from the sieve analysis of the formation materials. The average size of gravel pack materials should be 4 to 6 times as large as the average size of the aquifer materials.

Gravel pack material should consist mainly of particles of silica. The total amount of calcium carbonate particles should not exceed 5 percent in any gravel pack material because if acid treatment is required later, most of the acid's dissolving capabilities will be expended on the calcium carbonate particles in the pack materials rather than on the incrusting deposits on the screen. Shale, iron, anhydrite, or gypsum are undesirable in pack materials.

Since the design theory of gravel packs is based on mechanical retention of the formation particles, only a very thin pack is required. However, for ease of installation and to insure that an envelope of gravel will surround the entire screen, a minimum pack thickness of 3 inches and a maximum thickness of 8 inches is recommended. Increasing the thickness of the gravel pack is false economy and will not reduce the sand pumping.

If the gravel pack material is poured in from the top of the well, different sizes may become separated during placement. This is undesirable. Layers of fine material may also form and allow the aquifer sand to pass through into the well.

To prevent particle segregation and bridging, a tremie (a pipe which extends to the bottom of the well) is used. The tremie is filled with the gravel pack material and then slowly retracted from the well.

Screen and Casing

The screen and casing materials should be selected on the following basis: the mineral content of the ground water (incrusting or corroding tendencies) and strength requirements.

From the chemical analysis of the ground water, general incrustation or corrosion tendencies can be determined. Generally, ground waters used for irrigation contain minerals of an incrusting, but not corrosive nature. An acid treatment can control incrustation. Heavier screen and casing are recommended to withstand this treatment. Table 2 gives recommended gauges of steel casing for various depth and diameter irrigation wells that may require acid treatment. If corrosion, but not incrusting, tendencies are detected, don't use steel casing.

Metal casings should be standard gauge, hot rolled, and painted with a rust inhibitive paint or galvanized. All joints should be welded or riveted sufficiently to develop a structural strength equal to unseamed portions.

Table 2. Recommended gauges for steel or galvanized steel casings in irrigation wells

Depth of well (feet)	Diameter of plain and perforated casing (inches)				Diameter of corrugated metal pipe (inches)		
	12	14	16	18	12	15	18
	- - - - - gauge - - - - -				- - - - gauge - - - -		
0-100	12	10	10	10	12	12	12
100-200	10	10	10	10	12	12	12
200-500	10	10	10	10	12	12	10

Table 3. Recommendations for concrete casings in irrigation wells

Internal diameter (inches)	Shell thickness (inches)	Strength test requirements for perforated reinforced concrete well casings	
		Load to produce 0.01 inch crack, lbs./lin. ft. of barrel	Ultimate load, lbs./lin. ft. of barrel
12	2	1,620	2,430
13	2	1,665	2,630
17	2½	1,920	2,880
18	2½	1,980	2,970
25	3	2,200	3,300
26	3	2,250	3,360

Whether highly mineralized water produces incrustation or corrosion in concrete casing has not been fully investigated. Some experts say incrustation will occur on concrete casing and others are convinced it will not. It probably depends on the type and concentration of minerals in the water, composition of the aquifer and gravel pack, and drawdown. No conclusive information is available to prove or disprove that incrustation will form on concrete. However, concrete casing cannot be acidized as severely as steel casing and if heavy incrustation occurs on concrete casing, no known corrective procedure is available.

To insure sufficient structural strength, concrete casings should be the thickness and test strength shown in table 3, and have a minimum compressive strength of 4,000 pounds per inch after 28 days of curing, or the equivalent accomplished by using high pressure steam. The casing should also have at least two vertical holes through the shell to accommodate 5/16 inch alignment cables.

Screen Length and Diameter

The screen is the "heart" of any well and should be selected to fit the specific conditions. In selecting a well screen, a screen as long as possible is desirable for high capacity and a screen as short as possible is needed to provide more available drawdown.

The length and diameter of the screen are determined by desired capacity of well, thickness of the aquifer, and cost of the screen. Since it is not recommended that the pump extend into the screened area of the well, the pump selection should not be a consideration in screen selection.

In an artesian aquifer that has the same material throughout, screening about 70 to 80 percent of the aquifer thickness is the optimum design: i.e., provides the most water for screen investment. Where artesian aquifers are quite thick, it is desirable and more economical to screen less than 70 percent of the aquifer thickness.

In a water table aquifer, theory and experience have also shown that the well screen should be installed only in the bottom one-third of the formation. This will allow using two-thirds of the maximum available drawdown, which will deliver 90 percent of the maximum possible yield of the well. The drawdown-yield relationships for both water table and artesian aquifers are shown in figure 4.

Table 4 shows the yield and drawdown information for a water table well. Note that very little extra yield is obtained by a drawdown in excess of 67 percent of the total available drawdown. In fact, only an additional 10 percent yield can be obtained by using all of the available drawdown. Not only do pumping costs increase, but the excessive drawdown will have detrimental effects on the well screen.

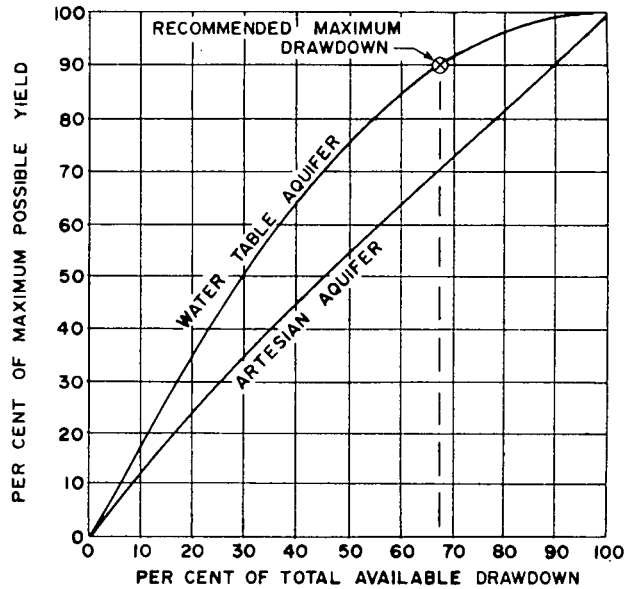


Figure 4. Drawdown—yield curves for water table and artesian aquifers

Table 4. Well yield and drawdown for a water table well

Percent of maximum available drawdown	Percent of maximum well yield
0	0
10	17
20	35
30	50
40	64
50	76
60	84
67	90
70	92
80	96
90	98
100	100

Pumping the water table down below the top of the screen dewaters a part of the screen. The dewatered section no longer contributes to the flow into the well. The velocity of flow through the remainder of the screen must increase, and rate of incrustation will increase.

Since the bottom 33 percent of the total available drawdown only adds 10 percent to the well yield, it is not considered economical to draw a well down more than two-thirds of the total available amount.

Screen Openings

It is desirable to have the screen openings tapered with the smaller opening on the outside of the screen.

Then any particle which will enter the opening will continue into the well and can be removed during well development.

The practice of opening a portion of the casing with chisels, picks, cutting torches, or other mechanical devices (other than methods used in commercial manufacture) to form a screen area is not desirable.

For a gravel pack well, the size of screen openings should be selected to keep at least 90 percent of the gravel pack material on the outside of the screen. About 10 percent will pass through the screen during well development.

For nongravel pack construction, the screen openings should pass 60 percent of the formation and prevent 40 percent from passing. The size of the screen opening must be determined by a sieve analysis of the formation materials.

The screen should have sufficient open area to allow water to enter at velocities no greater than 0.1 foot per second. This requires that there be at least 2.25 square feet of screen opening for each 100 gpm of the expected pumping rate. For example, if the expected pumping rate is 1,000 gpm, the total open area of the screen must be at least 22.5 square feet.

Since the saturated thickness of the aquifer limits the maximum effective length of the screen, the type of screen construction and the screen diameter must be selected to provide for the required open area.

The bottom of the well must be sealed to prevent any of the water bearing formation from entering. The screen may have a sealed bottom or a concrete plug may be used on an open end screen. The screen may be set into a clay layer far enough to prevent backwashing of the well bottom each time the pump stops and water flows back down the well. If the bottom of the well is eroded in this manner, sand and gravel can enter and decrease well capacity.

Developing the Well

Proper well development is as important as proper well construction. Failure to properly develop a well may reduce its potential yield by half or more. For example, it is an extremely bad practice to start pumping a well with a new pump, run at full or near the expected capacity of the well. This frequently moves too much sand at once into the gravel pack and results in sealing off the flow of water into the well.

The well should be developed as soon as possible after construction is completed. With gravel-packed wells, development is usually done by pumping. *A new pump owned by the customer should not be used to develop the well.* Fine sand particles removed during well development will cause excessive wear on a new pump.

To develop a well by pumping, the well is pumped slowly at first until the water is relatively free of sand and other foreign material. Then the well is pumped at a slightly higher rate until the water is again free of sand and foreign material.

This procedure should be continued until the maximum development pumping rate is reached. The maximum development rate may be reached when the pumping water level in the well drops to the top of the screen, i.e., two-thirds of the maximum available drawdown.

Where drawdown does not limit the well capacity, the maximum development rate should be a flow 25 percent greater than the anticipated pumping rate.

The well should be pumped at the maximum development rate until the water is relatively free of sand and foreign material, and the pumping water level remains stable for at least 2 hours of pumping.

The well driller should have, as part of his equipment, a pump and power unit of sufficient size to perform well development by pumping. Flow rate should be measured by an orifice or equivalent means to an accuracy within 5 percent. Drawdown should be measured by an air line or electrical contact device.

Surging is the process of moving water from inside the well screen out into the formation. This may be accomplished by moving a surge block, which acts as a piston inside the well casing, up and down. Other methods of surging are by using compressed air or by frequent intervals of starting and stopping the pump.

In the development process, particles may tend to "bridge" as they move toward the screen. Reversing the flow direction breaks up the bridges and the particles can then be removed by pumping or by bailing. A bailer is a section of pipe with a check valve in the bottom. It may be fitted with a plunger to produce a vacuum that opens the check valve and sucks sand into the bailer.

Another method often used to agitate the formation is the water jet. A stream of water at high speed is directed into the screen openings. The stream penetrates into the formation and loosens the fine particles so they can be removed during the next pumping operation.

Surging and removal of the sand from the well should continue until little or no sand is pulled into the well.

Testing the Well

The well must be test pumped to determine the correct pump size, number of stages or bowls, size of power unit required, and to obtain a pumping plant of high efficiency with minimum power or pumping costs. Often, an accurate test of the well before pump purchase will more than pay for itself in the first cost of equipment and in operating costs. To buy a pump, power unit, and sprinkler irrigation system without a pumping test of the well is like ordering a suit of clothes without giving any measurements.

It is the well driller's responsibility to test the well for output and drawdown characteristics with his test pump. *Under no circumstances should a customer's pump be used for developing or testing a new well.*

The static water level should be measured with a standard electrical or air pressure device prior to test pumping. After test pumping is completed, the water level in the well should be measured 1 minute after the pump is stopped and again 5 minutes later. Another water level measurement should be made after removal of the test pump. These measurements should be recorded with the other well test data.

Test Pumping Rates

Wells which yield more than 125 percent of the desired pumping rate should be pumped at a constant rate equal to 125 percent of the desired pumping rate for a minimum of 24 hours. The flow rate should be measured with a standard orifice or other measuring devices, accurate to within 5 percent. The horizontal trajectory method of measuring flow, explained in Agricultural Engineering M-147, *Estimating Water Flow by the Trajectory Method* is not accurate enough for well testing. The "barrel" method should not be used since it does not provide a continuous measurement of the flow rate.

At the end of 24 hours, the pumping water level should be measured and recorded. The flow rate should also be recorded.

The discharge should then be reduced to approximately the desired pumping rate and after the discharge and water level in the well have remained constant for at least 30 minutes, they should be recorded.

This process should be repeated for discharges of approximately 75 and 50 percent of the desired pumping rate.

When the well is not capable of yielding 125 percent or more of the desired pumping rate, it should be test pumped at a drawdown not to exceed two-thirds of the saturated thickness of the aquifer for a minimum of 24 hours. The pumping rate must be adjusted so drawdown does not exceed two-thirds of the saturated aquifer thickness.

It is extremely important to remember that *if the water drawdown level approaches the top of the screen, the maximum at which the well should be pumped has been reached.*

After 24 hours the pumping water level can be measured and recorded. The flow rate should also be measured and recorded. This flow rate may be called the optimum well discharge.

The test pumping rate should be decreased to 80 percent of the optimum well discharge, and after the discharge and drawdown have remained steady for 30 minutes, these measurements should be recorded. The process should be repeated for pumping rates of 60 percent and 40 percent of the optimum well discharge. Each pumping rate should continue until the water level remains steady.

The pump should not be stopped during the test pumping period. If for any reason the pump is stopped for less than 1 hour, the test may be resumed but no drawdown or yield measurements should be recorded until the water level in the well has remained steady for 1 hour. If the pump is stopped for more than 1 hour, the test should not be resumed until the well has been pumped at the maximum test rate for a period equal to the shutdown period.

Test Pumping Data

Sample drawdown and yield data are shown in table 5. There are 100 feet of total available drawdown in the well. However, the optimum well discharge is at a drawdown of 67 feet or a pumping level of 92 feet from the ground surface. The top of the screen is at 92 feet and thus the screen is not dewatered at this pumping rate. The well was also test pumped at rates equal to 80, 60, and 40 percent of the optimum yield of 900 gpm.

The test pumping data from table 5 can also be presented in a curve as shown in figure 5. The dashed line indicates yield values estimated but not determined by actual test. It can be seen from the curve that very little extra yield can be obtained by dewatering the screen. The small increase in yield is more than offset by increased pumping costs and decreased well life.

Sealing and Abandonment

To avoid intermingling waters from different formations, any abandoned bore hole, including test holes, should be filled with material which conducts water more slowly than any material removed from the hole.

Disinfect the Well

The driller should completely disinfect the newly constructed well and equipment to destroy any bacterial accumulations. Iron bacteria can be very detrimental to the well screen. They do not cause disease but live on the iron in the water or on the iron in the pump, pipe, and fittings. The bodies of dead iron bacteria will plug the well screen and are very difficult to remove.

Iron bacteria are normally transmitted by well drilling tools. Thus, each well and irrigation pump should be thoroughly disinfected. Use 2 gallons of common laundry bleach for each 1,000 gallons of water in the well casing and screen (1 cubic foot=7.5 gallons). Mix the laundry bleach with 12 parts of water to minimize corrosion when adding it to the well.

Be sure the chlorine solution gets to the bottom of the well. Starting and stopping the pump quickly several times will help to distribute the chlorine throughout the

Table 5. Sample test pumping data*

Distance from ground surface to pumping water level (feet)	Drawdown (feet)	Well yield (gpm)
92	67	900
71	46	720
58	33	540
45	20	360

* Static water level is at 25 feet.

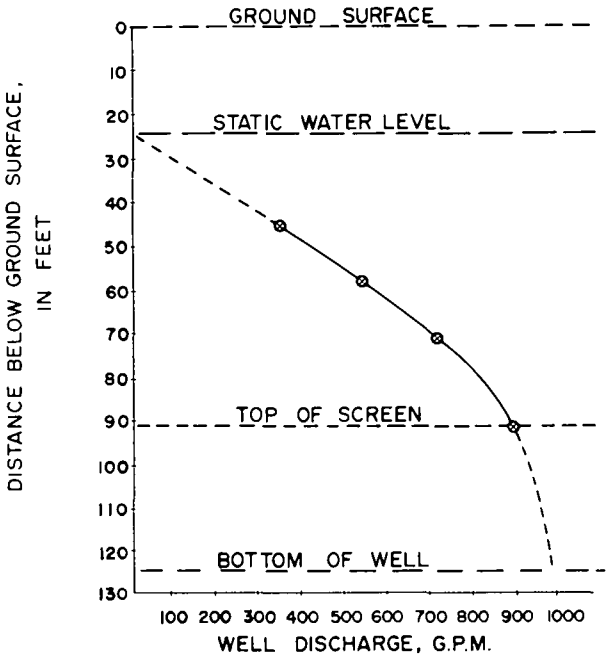


Figure 5. Drawdown vs. pumping rate

well. Allow the chlorine to remain in the well at least overnight.

An annual chlorination of an irrigation well is an excellent safety precaution.

Driller's Information to Customer

A copy of complete well specifications together with all development and test data should be supplied by the driller to the purchaser for a permanent record.

This information is particularly valuable for evaluating changes in well yield and possible well maintenance. For example, an increased drawdown at a given pumping rate with no decrease in static water level might mean screen incrustation. Information on screen construction, diameter, depth, and length will be necessary before acidizing the well.

It is not unusual for an irrigation system to be expanded and consequently require a greater flow rate. Information on drawdown and pumping rate are absolutely necessary to decide if the well will yield more water than is presently used.

Thus it is essential that the owner receive complete information on his irrigation well to be kept as a permanent record. A suggested information form is on page 9.

Both development and testing must be performed before the irrigation well is considered finished. The purchaser of the well should be aware of the necessity for developing and testing the well and be willing to pay for these services.

Measure Drawdown During Pumping Season

One of the best methods for measuring static water level and drawdown is use of an air line, which can be installed easily, permanently, and inexpensively. The air line is usually ⅛- to ¼-inch copper tubing or galvanized pipe long enough to extend below the lowest level to be measured. The air line may be fastened to the pump column and installed with the pump. The air line must be airtight and all joints connected carefully. The vertical length of air line from the center of the pressure gauge to the bottom of the line should be measured carefully and recorded at the time of installation.

A pressure gauge is attached to the air line at the surface and an ordinary tire valve outlet is provided to permit attaching a tire pump. It is desirable to use an altitude pressure gauge reading directly in feet of water.

For a discussion of the air line method and the need for well performance records, see M-151, *A Health Record for Irrigation Wells.*

Summary

- Obtain a water use permit from the Department of Natural Resources before proceeding with an irrigation well.
- Have a written contract to cover test hole drilling, well construction, well development, and well testing with a reputable contractor.
- Have adequate test drilling.
- Select the screen and design the gravel pack from the sieve analysis of the water bearing formation.
- It is a waste of money to screen more than the bottom one-third of a water table aquifer.
- Do not allow the pumping water level to drop lower than two-thirds of the maximum available drawdown or below the top of the well screen.
- Proper well development is as important as proper well construction.
- The well should be test pumped at least 24 hours at the maximum rate.
- Four different pumping rates and draw-down levels should be measured and recorded.

- The pump to be used for the irrigation system should not be selected until the well is developed and tested.
- Disinfect the well to kill iron bacteria.
- Obtain complete information on the well from the driller.
- Install an air line and keep a continuous "health" record of the irrigation well.

Irrigation Well Specifications

Owner_____ Address_____

Location of well: ____¼, ____¼, of Section_____,
Township_____, Range_____, County of_____.

Casing:_____ feet of _____ inches diameter
casing material is_____. Wall thickness
or gauge is_____. Corrosion of metal
casing inhibited by:

Screen:_____ feet of_____
inches diameter connection between screen and casing by_____.
Material of screen_____. Type of screen construction_____.
_____ square inches of screen openings per square foot of screen; or _____
square inches of screen openings per lineal foot of screen.
Type of screen opening:
Continuous slot_____
Louver or shutter_____
Cut slot_____
Punched slot_____
Punched hole_____
Bottom of screen is plugged by_____.

Depths:

Item	Distance below ground surface, in feet
Bottom of casing	
Bottom of screen	
Static water level before test pumping	
Water level 1 minute after completion of pumping test	
Water level 5 minutes after completion of pumping test	

Pumping Test:

Flow measuring device used was _____.

Test started at ____a.m., p.m., _____, 19____.

Date of reading	Time of day of reading	Flow rate gpm	Distance to water level, in feet below ground surface	Drawdown in feet

Attach information on mechanical analysis of formation and copy of sand analysis curve showing cumulative percent retained versus grain size.

Suggested Test Well Agreement*

I. Test wells to be on the property of _____, located in Section _____, Township _____, Range _____, County of _____.

II. Test wells shall be drilled to investigate unconsolidated (sand and gravel) water bearing formations. Location of the test wells shall be by mutual agreement of the driller and landowner. The number of test holes shall not exceed _____. The cost of the test holes shall be $_____ per foot, which includes collecting the information in part III.

III. The following information shall be collected for each test hole:
1. Identification and location of the site.
2. Information on the layers penetrated, called the log of the test hole, including descriptions, depths, and thicknesses of all different layers, both water bearing and nonwater bearing that are penetrated during the drilling.
3. Representative samples of the strata penetrated.
4. Depth to the static water level in each water bearing formation.
5. Samples of water from aquifers which indicate potential yield.

IV. Where water is present in unconsolidated formations, a sieve analysis shall be performed on the representative samples of each test hole that shows promise. A sand-analysis curve showing cumulative percent retained and grain size, in thousandths of an inch, shall be drawn and a copy provided to the landowner. The total fee for the sieve analysis and sand-analysis curve shall be $_____.

V. The information from the test holes shall be used to determine the location of the irrigation well, by mutual agreement of the landowner and well driller.

VI. Test well drilling may be stopped at any time by the landowner by notifying the driller in writing. The landowner will pay for the drilled depth.

VII. The well driller agrees to insure himself against all claims that may arise from any injury to his crew or himself while on the drilling job and absolves the owner from all responsibility in this matter.

VIII. Work shall begin not later than _____, 19____ and shall be continued until its completion according to the conditions of this contract.

IX. Water supply when drilling (specify who will supply water for drilling and charges, if any):

The undersigned hereby submits this bid according to the above conditions:

Date _____

Accepted:

Date _____

Witness _____

Witness _____

Name _____

Address _____

Owner _____

Address _____

Irrigation Well Agreement*

I. An irrigation well to be constructed, developed, and tested on the property of _____, hereafter called the purchaser, located in Section _____, Township _____, Range _____, County of _____.

II. The irrigation well construction, development, and testing is to be performed by _____, hereafter called the drilling contractor, using his equipment.

III. As determined by test drilling a water supply of approximately _____ gallons per minute should be found in the _____ formation. Estimated depth to bottom of well is _____ feet.

IV. The nominal diameter of the well shall be _____ inches.

V. Specifications of the screen are as follows:
1. Nominal diameter _____.
2. Material _____.
3. Type of opening _____.
4. Dimension of opening _____.
5. Percent of open area _____.
   or open area per square foot _____.
   or open area per lineal foot _____.
6. Length of screen is _____ feet.
7. The top of the screen shall be _____ feet from the ground surface and shall extend to a depth of _____ feet.
8. Where a gravel pack is used, the well screen openings shall retain 90% or more of the gravel-pack material.

VI. Specifications of the casing are as follows:
1. Nominal diameter _____.
2. Material _____.
3. Wall thickness _____.
4. Weight per lineal foot _____.
5. Type and amount of protection against corrosion:

VII. The casing shall extend at least 12 inches above ground level or above flooding conditions, to the top of the screen for a total length of _____ feet.

* Formal contract should be drawn by an attorney.

VIII. The gravel pack shall be designed in accord with recommendations of the well screen manufacturer based on the test hole sand-analysis curve. The gravel pack material shall be clean, with well-rounded grains that are smooth and uniform. If the well screen and casing material will withstand acid treatment to remove incrustation, the total amount of calcium carbonate particles in the gravel pack shall not exceed 5 percent. The gravel pack shall be _____ inches thick.

The gravel pack shall be filled from the bottom of the well upward by use of a tremie pipe in order to prevent separation and layering.

IX. The following costs shall apply to the well construction:

Depth in feet	Cost of casing per foot installed	Cost of perforated screen per foot installed	Cost of gravel packing per foot	Total cost
0 to _____				
_____ to _____				
_____ to _____				
_____ to _____				

Total cost of well construction and materials $_____

X. Water supply when drilling (who will supply water for drilling and charges, if any):

XI. Development of the well:

1. To remove fine sand, silt, and clay particles in the water bearing formation adjacent to the well screen, development shall proceed as soon as possible after completion of well construction.
2. With a gravel packed well, development shall be by pumping.
3. In no case shall a new pump owned by the purchaser be used to develop or test pump the well.
4. The well shall be pumped at a constant rate not to exceed 20 percent of the estimated maximum capacity until the water is relatively free of sand or other foreign material. Flow rate shall be measured by an orifice accurate within 5 percent.
5. This procedure shall be followed in increments of 20 percent of the estimated maximum capacity until maximum capacity is reached or until a capacity of 20 percent greater than the anticipated pumping rate is reached. Maximum capacity shall be defined as the flow at two-thirds of the available drawdown.
6. The well driller shall furnish a pump and power unit of adequate size to develop the well by pumping.
7. Where appropriate, development methods such as using a surge block, compressed air, water jet or backwashing may be used.
8. The cost of developing the well shall not exceed $_____.

XII. Test Pumping

1. Test pumping shall not begin until the well is fully developed.
2. Under no circumstances shall the puchaser's pump be used for testing a new well.
3. The pump and power unit used for testing shall be capable of continuously pumping the well at all of the rates and for all durations set forth in these requirements.
4. All water level measurements shall be made with a standard electrical or air pressure measuring device.
5. All discharge rates shall be measured with a standard orifice, propeller meter or equivalent water flow measuring device with an accuracy of plus or minus 5 percent.
6. The static water level shall be measured prior to test pumping. After test pumping is completed, the water level in the well shall be measured 1 minute after the pump is stopped and again 5 minutes later. Another water level measurement shall be made after removal of the test pump. These measurements shall be recorded with the other well test data.
7. Wells which are capable of yielding more than 125 percent of the desired pumping rate shall be pumped at 125 percent or more of the desired pumping rate for a minimum of 24 hours. Then measurements of discharge and water level in the well shall be recorded. The discharges shall then be reduced to approximately the desired pumping rate and after the discharge and water level in the well have remained constant for a minimum of 30 minutes, they shall be recorded. This process shall be repeated for discharges of approximately 75 percent and 50 percent of the desired pumping rate.
8. If the well is not capable of yielding more than 125 percent of the desired pumping rate, it shall be tested by first pumping at a drawdown not to exceed two thirds of the saturated thickness of the aquifer for a minimum of 24 hours. The pumping rate and the water level shall be measured and recorded. This pumping rate shall be called the optimum well discharge. The pumping rate shall then be decreased to 80 percent of the optimum well discharge and after the discharge and drawdown have remained steady for 30 minutes, these measurements shall be recorded. The process shall be repeated for pumping rates of 60 percent and 40 percent of the optimum well discharge.
9. At no time during testing shall the pump be stopped unless absolutely necessary. If for any reason the pump is stopped for a period of less than 1 hour, the test may be resumed but no drawdown or yield measurements may be recorded until the water level in the well has remained stable for more than 1 hour. If the pump is stopped for more than 1 hour, the test may not be resumed until the well has been pumped at the maximum test rate for a period equal to the shutdown period.
10. The customer shall be furnished with a signed well testing report containing all of the data obtained from requirements 6, 7, and 8. He shall also be furnished with a graph of drawdown versus pumping rate as developed from requirement 7 or requirement 8. In addition, the report shall show the customer's name, legal description of well location, date of test, permit number, measuring devices used, and any other pertinent data.
11. The cost of test pumping and providing the information in requirement 10 shall not exceed $_____.

XIII. Work shall begin not later than _____, 19_____ and shall be continued until its completion according to the conditions of this document.

XIV. All operations performed under this contract shall be subject, unless otherwise herein provided, to the following:

Covenants and Agreements

A. The Drilling Contractor:

1. Shall furnish all labor, tools and machinery necessary to carry out his part of this contract, and shall prosecute the work under this contract diligently and in good workmanlike manner.

2. Agrees that the purchaser will not be responsible in cases of any accident or injury to persons or employees in connection with the drilling operations, and further agrees to carry the necessary insurance to cover such situations.
3. Agrees to save harmless the purchaser from any and all liens for material and labor supplied by the drilling contractor.
4. Agrees to keep an accurate record of the character of all strata passed through in the drilling, of water levels, of casing used, of perforations made (if any), and of the size and location of any and all other materials and equipment installed, and to furnish the purchaser with a copy of same upon completion.
5. Warrants that the well (wells) shall be serviceably straight, round, and aligned, and of full size, so as to allow the installation and operation of pumping equipment designed for a hole of that nominal diameter.
6. Warrants that, unless otherwise specifically stated herein, all materials and equipment installed shall be new, of standard good quality, and not contain, to his knowledge, any flaws or defects.

B. The Purchaser:

1. Hereby warrants that he has full right and authority to enter into this contract and to authorize the drilling contractor to drill upon the above described land.
2. Does hereby grant to the drilling contractor, his officers, agents, and employees, full right to ingress and egress to and from said above described land for the purpose of performing this contract and doing such acts incidental thereto as may reasonably be necessary in connection with such performance.
3. Will provide, at no charge to the drilling contractor, such space at the drill site and its proximity, as the drilling contractor may desire for pits, dumps, machinery, and the storage of material and equipment which may be required under this contract, and save the drilling contractor harmless in the event of accidental damage to crops, buildings, trees, fences, walks or any other property upon or adjacent to such site.
4. Hereby permits the drilling contractor to dump all drill cuttings, water, and debris taken out of the hole during the progress of the work, around and about the drill site at such places and in such manner as the drilling contractor may choose and the drilling contractor shall not be called on to remove the same.
5. Hereby takes full responsibility for selecting the exact site of the drilling, and any statements made by the drilling contractor are suggestions only and shall not be construed as representations as to where the hole should be drilled. However, the drilling contractor shall make such suggestions as he deems pertinent to location from the sanitation viewpoint, especially with respect to State Health Department rules, regulations or recommendations.
6. Hereby agrees that the drilling contractor shall at any time after ten (10) days of purchaser's default in payment as herein provided, have the right and permission to go upon the premises without guilt of trespass and reclaim and recover any materials installed by the drilling contractor in the hole, including casing. It is specifically agreed that casing and all other material installed in the hole by the drilling contractor shall be deemed personal property unattached to the realty until fully paid for as herein provided.

C. It Is Understood and Agreed By Both Parties:

1. That neither can tell exactly what will be found underneath the surface of the earth and that the work of the drilling contractor hereunder is subject to those conditions which he may find underneath the surface therefore:
   a. The drilling contractor does not agree to find or develop water, nor does he represent, warrant or guarantee the quantity, or kind of water, if any, which may be encountered. All operations are at the risk of the purchaser and failure to strike water shall in no way release the purchaser from payment of the full contract price.
   b. The drilling contractor shall drill the hole (holes) with the diameter and casing sizes as specified here as long as such a program remains practicable considering the nature of the material being drilled. When, in the opinion of the drilling contractor, it becomes impractical to proceed as specified, he may proceed with the drilling using that smaller size hole diameter and casing size most practicable to be used, unless the purchaser deems it impracticable for his purposes and orders the drilling contractor to discontinue all drilling operations. The drilling price shall remain the same as for the specified size, unless otherwise herein specifically provided.
   c. The drilling contractor shall not be liable for any damage arising out of any delay or failure due to the hazards of drilling, but in the event of unreasonable delay or failure, this contract may be terminated by the purchaser, upon payment to the drilling contractor for all drilling done and materials installed.
2. That the starting date set forth is an approximate date only, it being agreed that if the drilling equipment necessary for the work herein contemplated is, without fault of the drilling contractor, detained on other jobs, then the drilling contractor shall not be responsible or liable to the purchaser for any damages of any nature occasioned by any delay in commencing performance hereunder. In the event the commencement of performance hereunder by the drilling contractor is so delayed for a period of thirty (30) days, the purchaser may, at his option (to be exercised in writing, given to the drilling contractor on the day next succeeding the last day of the aforesaid period) terminate this contract and neither party shall in such event be liable to the other for any damages of any nature whatsoever.
3. That if the performance of any of the drilling contractor's obligations herein is materially hampered, interrupted, delayed, or interferred with by reason of fire, casualty, lockout, strike, labor conditions, unavoidable accident, riot, war (whether declared or undeclared), act of God, or by the enactment of any Municipal, State or Federal Ordinance or Law, or by the issuance of any executive or judicial order or decree, whether Municipal, State or Federal, or by any other legally constituted public authority, or by any other cause beyond the reasonable control of other cause beyond the reasonable control of the drilling contractor, then during the continuance of any such event, the drilling contractor, at his sole option, shall be relieved of the performance of his obligations herein.
4. That this agreement shall inure to the benefit of and be binding upon the heirs, legal representatives, successors, and assigns of the parties, respectively.
5. That this instrument contains the entire agreement between the parties hereto and that no warranty, expressed or implied, representation, promise, statement or inducement made by either party hereto or by any agent or employe of either party, which is not contained in this written agreement shall be binding or valid.

WITNESSES:

_____ Drilling Contractor

_____

_____ Purchaser

AGRICULTURAL EXTENSION SERVICE • UNIVERSITY OF MINNESOTA

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Nitrogen Fertilizer Injection

Roger E. Machmeier, extension agricultural engineer

The application of plant nutrients through irrigation water is frequently called "fertigation" and the application of nitrogen "nitrogation." These practices have been used with varying degrees of success in selected areas of the United States since about 1930.

Advantages

One major advantage of applying fertilizer through an irrigation system is that the labor required is only slightly more than the labor required for irrigation alone. While the surface distribution of the plant nutrients is only as good as the distribution of the irrigation water, excellent control can usually be maintained on he depth of nutrient location, particularly nitrogen (N).

Nitrogen is by far the most practical plant nutrient to add through irrigation water. It is completely water soluble and becomes available to plants when it is applied with the irrigation water. If nitrogen is applied through the irrigation water in repeated small quantities as the plant needs it, less total nitrogen may be required through the growing season than if it were applied in a single large amount at the beginning of the growing season. This statement is particularly true regarding light sandy soils where considerable leaching may take place particularly under irrigated conditions. Sandy or sandy loam soils do not have the capacity to store large amounts of nitrogen and hence this nutrient is not available to the crop as it approaches maturity.

Most crops require a continuing supply of nitrogen throughout the growing season. This need will vary as to the stage of maturity of the crop. Table 1 shows the use of nitrogen by corn during various growth stages. Column (3) of table 1 shows that the greatest use of nitrogen by the corn plant is at 40 to 50 percent maturity. However, the table also shows that the need for nitrogen by the corn plant continues until the corn is mature. From 80 to 100 percent of maturity, it requires 16 percent of the total N used.

The supply of nutrients and the uptake by the plant late in maturity is important to prevent loss of nutrients from the leaves. This loss by translocation into the grain may cause necrosis of the leaves, which can result in a loss in the carbohydrate assimilation capacity of the plant. A late season firing of corn leaves which may be noted with a nitrogen or potassium deficiency is likely to result in a yield loss.

Many authorities say that on sandy soils which are droughty, the nitrogen should be added with the irrigation water. By adding nitrogen with each application of irrigation water, the plant is supplied with this nutrient as needed. There is considerable evidence to support the idea that on sandy or sandy loam soils, nitrogen should be applied in continuing amounts during the growing season.

Most of the nitrogen which is absorbed by the corn plant is in the form of nitrate (NO_3). However, nitrate cannot be stored in sandy soil except in very small amounts because it is water soluble and subject to leaching and denitrification. Denitrification is a process by which bacteria act on the nitrogen compounds in the soil and release gaseous nitrogen to the soil air. This nitrogen is lost for use by the plant. Nitrogen which is lost from the crop root zone represents an economic

Table 1. Use of nitrogen (N) by corn during growth

(1) Percent of maturity	(2) Cumulative percent of total N used[1]	(3) Percent of total N used in period	(4) Cumulative amount of N used, pounds	(5) Amount of N used in each period, pounds
0	0		0	
		1		2
10	1		2	
		5		10
20	6		12	
		7		14
30	13		26	
		18		36
40	31		62	
		22		44
50	53		106	
		11		22
60	64		128	
		10		20
70	74		158	
		10		20
80	84		168	
		8		16
90	92		184	
		8		16
100	100		200	

[1] From figure 61, *Modern Corn Production*, Samuel R. Aldrich and Earl R. Leng, F & W Publishing Corp., Cincinnati.

loss not only from the fertilizer lost but from the resultant decrease in crop yield.

Nutrient uptake by the plant tends to increase as the yield increases. Plants have a critical need level for each nutrient. If uptake falls below the need, crop yield potential is reduced. If, however, the nutrient is present in concentrations above the critical level, then additional applications of the nutrient will not increase yield.

It is more practical to apply phosphorus and potash fertilizers as a top dressing prior to tillage operations so that these nutrients are distributed throughout the upper soil horizon. Research has shown that these nutrients, when applied through the irrigation water, will fix as soon as they come in contact with soil particles. This is particularly true of phosphorus. Repeated heavy applications on the surface of the soil do not penetrate downward more than 2 or 3 inches even when exposed to extreme leaching.

Disadvantages

There are certain disadvantages to applying fertilizers through irrigation systems. An improperly designed system which does not give equal distribution of water will not give equal distribution of plant nutrient. With a continuous moving system it is necessary to use a solution in which the nitrogen concentration is constant. Thus, it may not be possible to use lower cost fertilizers which could be diluted in water. For set-type irrigation systems where the lateral line or the sprinklers cover an area for a specified period of time, the nitrogen solution can be mixed by the farmer. However, where a continuous-move system is used, the concentration of nitrogen in the fertilizer solution must be constant and pumped into the system at a constant rate. Nitrogen fertilizer in this form is more costly.

Another disadvantage is that it is not possible to place fertilizer in specific locations in the soil such as the conventional band applications. However, nitrogen applied through the irrigation water will be distributed throughout the root zone of the soil.

When irrigation systems are improperly designed so that the application rate exceeds the maximum soil infiltration rate, runoff will occur. This runoff will be more critical when plant nutrients are being supplied with the irrigation water since the distribution of the plant nutrients is the same as the distribution of the irrigation water. It might be argued that if water is not being supplied to the crop, then it is unnecessary to apply plant nutrients. However, the important thing to keep in mind is that the distribution of plant nutrients injected through an irrigation system is no better than the same system's distribution of water.

With a set-type irrigation system, it has been established that water distribution over the area improves as the number of irrigations increases. That is, the evenness of distribution of the total water for a number of irrigations will improve over a single irrigation. Hence, the distribution of fertilizer injected in small amounts through each application of irrigation water tends to improve for successive applications of irrigation water. For even distribution, it is important that each of the water applications contains some plant nutrients.

IRRIGATION SYSTEMS

Set-Type Systems

Liquid nitrogen fertilizer can be applied with any type irrigation system. With a set-type system, either hand or mechanical move, the area covered by the lateral can be calculated as follows:

$$\text{Area covered} = \frac{L \times S}{43{,}560}$$

Where L = the distance wetted along the lateral, feet
S = the distance between lateral moves, feet
43,560 = the number of square feet per acre

For example, a 1,290-foot lateral will cover 1,320 feet (80 rods) and may have a set distance of 60 feet. The area covered is equal to:

$$\frac{1{,}320 \times 60}{43{,}560} = 1.82 \text{ acres}$$

The area can also be determined with table 2. If the sprinklers are spaced 40 feet apart, there are 33 per 1,320 feet. Using the value of 0.0551 for the 40 x 60 spacing and multiplying by 33, results in an area of 1.82 acres. Thus, either the formula or table 2 can be used to compute the area covered by the lateral.

For boom or volume gun sprinklers, the same formula may be used with L as the distance between lanes and S as the distance between sets in the lane. For a 280-foot lane spacing and a 240-foot set distance, the area covered per set is:

$$\text{Area covered} = \frac{280 \times 240}{43{,}560} = 1.54 \text{ acres}$$

The same value can be obtained from table 3 for a lane spacing of 280 feet and a sprinkler setting distance of 240 feet. For settings other than these in table 3, the formula should be used. Manufacturers specifications on the area covered by a sprinkler should be checked since the maximum diameter is often used. When calculating the area covered, the actual setting distances must be used to account for overlap.

A nitrogen fertilizer solution is heavier than water's weight of about 8.3 pounds per gallon. Table 4 gives weights of liquid nitrogen fertilizers which are appropriate for injection.

With a continuous-move irrigation system, a commercially prepared urea-ammonium nitrate liquid fertilizer is the most appropriate. While these are some-

what more expensive sources of N, the convenience and the constant concentration are important considerations.

With a set-type irrigation system granular fertilizers such as ammonium nitrate can be dissolved and used. With this type system, it is not necessary to have a solution of constant concentration.

Anhydrous ammonia or any other nitrogen fertilizer that has free ammonia should not be applied through a sprinkler irrigation system. Much of the N will volatize and be lost to the atmosphere.

To calculate the amount of liquid nitrogen fertilizer required, first determine the amount of actual N to apply per acre. Then multiply the value in column (5) of table 4 by the acres per lateral or sprinkler set and then by the amount of actual N to be applied per acre.

For example, if 25 pounds of actual N is to be applied per acre using a 28 percent urea-ammonium nitrate solution on a 1.82-acre lateral line set, the amount of liquid nitrogen fertilizer to apply is:

$$25 \times 0.335 \times 1.82 = 15.2 \text{ gallons}$$

With granular ammonium nitrate, which is 33 percent N, calculate the number of pounds required to apply the desired amount of N. Dissolve this with water in a container and inject into the irrigation water during the last half of the irrigation set time.

By applying the fertilizer some time during the last half of the set, the nitrogen will remain in the upper part of the soil profile and the amount of leaching that might result from a rainfall after the irrigation will be reduced.

It is usually a good idea to pump some fresh water through the irrigation system before shutting it off. The fresh water will wash off any fertilizer that may be on the plant leaves.

With a continuous-move system, the concentration of fertilizer in the irrigation water is so small that no damage will occur to the plants. With a continuous-move system, it would be impossible to apply fertilizer and wash it off the plant leaves. For continuously moving sprinklers, liquid fertilizer must be injected at a continuous rate for even application.

Center-Pivot

With a center-pivot, self-propelled sprinkler, the following formula can be used:

$$GPH = \frac{100\ AN}{PHW}$$

Where GPH = liquid fertilizer to inject, gallons per hour

A = total area actually irrigated by the center-pivot, self-propelled sprinkler, in acres

P = percent nitrogen in liquid fertilizer

N = actual nitrogen to be applied, pounds per acre

H = hours per revolution of sprinkler system

W = weight of 1 gallon liquid fertilizer, in pounds

For example, assume a 140-acre system rotating in 60 hours to apply 20 pounds of actual N per acre using a 32 percent N liquid fertilizer:

$$GPH = \frac{100 \times 140 \times 20}{32 \times 60 \times 11.06} = 13.2 \text{ gallons per hour}$$

Table 2. Area irrigated by one sprinkler

Sprinkler and lateral spacings	Area in acres
30 x 30	0.0207
40 x 40	.0276
30 x 50	.0344
30 x 60	.0413
40 x 50	.0459
40 x 60	.0551
60 x 60	.0826
60 x 70	.0964
60 x 80	.1102
80 x 80	.1469

Table 3. Area irrigated by one boom or volume gun sprinkler

Lane spacing, feet	Sprinkler setting, feet	Area in acres
180	160	0.66
180	180	0.74
200	180	0.83
200	200	0.92
220	200	1.01
220	220	1.11
240	200	1.10
240	220	1.21
240	240	1.32
260	220	1.31
260	240	1.43
260	260	1.55
280	240	1.54
280	260	1.67
280	280	1.80
300	260	1.79
300	280	1.93
300	300	2.07
320	280	2.06
320	300	2.20
320	320	2.35

Table 4. Weights of some liquid nitrogen fertilizers

(1) Kind of fertilizer	(2) Percent nitrogen	(3) Weight per gallon pounds	(4) Pounds of nitrogen per gallon	(5) Gallons of fertilizer to apply 1.0 pound per acre
Urea-ammonium nitrate	32	11.06	3.54	0.285
Urea-ammonium nitrate	28	10.65	2.99	0.335
Urea-ammonium nitrate	16	10.05	1.61	0.620

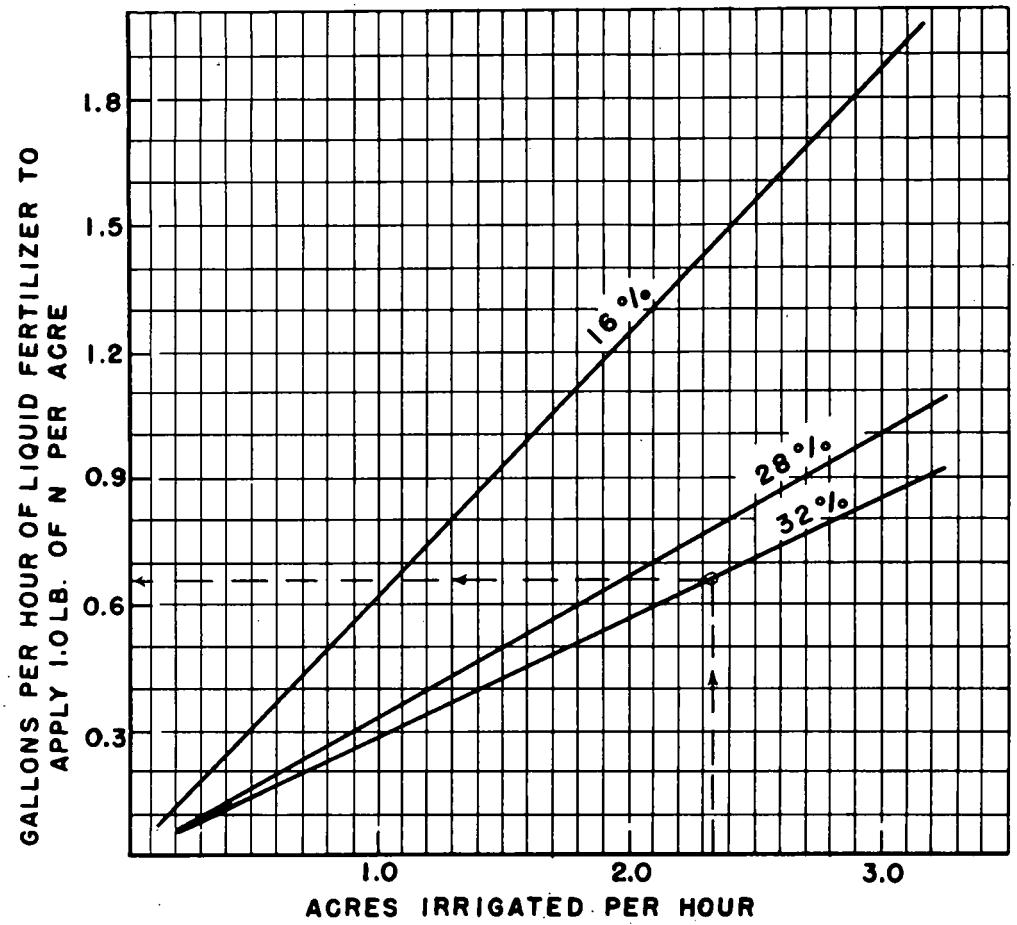

Figure 1. Rate of liquid fertilizer to inject for solutions of various concentrations

Thus, the 32 percent N liquid fertilizer solution must be injected at a continuous rate of 13.2 gallons per hour or at a rate of 0.22 gallons per minute to apply 20 pounds of actual N per acre.

The amount of liquid fertilizer to apply can also be determined by using figure 1. Using the same conditions as in the previous example, 140 acres divided by 60 hours is an irrigation rate of 2.33 acres per hour.

Using the value of 2.33, enter the figure on the horizontal axis and proceed upward to the 32 percent line. At this point proceed horizontally to the vertical axis and read the value of 0.66 gallons per hour to apply 1 pound of N per acre. Since the rate of application is 20 pounds per acre, multiply 20 by 0.66 for a value of 13.2 gallons per hour. This is the same value as obtained by the formula.

Continuous Move Boom or Volume Gun

For a self-propelled boom or volume gun using a flexible hose, the following formula can be used:

$$GPH = \frac{100\ SLN}{43{,}560\ PW}$$

Where GPH = liquid fertilizer to inject, gallons per hour
S = rate of sprinkler movement, feet per hour
L = distance between sprinkler lanes, feet
N = actual nitrogen to be applied, pounds per acre
P = percent nitrogen in liquid fertilizer
W = weight of 1 gallon liquid fertilizer in pounds

As an example, use a self-propelled boom moving at 100 feet per hour with 240 feet between lanes. It is desired to apply 20 pounds of actual N per acre using a 32 percent liquid nitrogen fertilizer. The rate of application is:

$$GPH = \frac{100 \times 240 \times 20 \times 100}{43{,}560 \times 32 \times 11.06} = 3.1 \text{ gallons per hour}$$

This rate must be continuously injected as the sprinkler moves. Figure 1 may also be used to determine the injection rate. The rate of irrigation must be calculated using the lane spacing and the sprinkler movement rate. In this example the irrigation rate is:

$$\frac{240 \text{ feet x } 100 \text{ ft. per hour}}{43{,}560} = 0.55 \text{ acres per hour}$$

Entering figure 1 on the horizontal axis with a value of 0.55 acres irrigated per hour, proceed upward to the 32 percent line. Then proceed over to the vertical axis reading a value of 0.15 gallons per hour of liquid fertilizer to inject in order to apply 1.0 pound of N per acre. The value of 0.15 must be multiplied by 20 pounds of total N to be applied. Thus, 20 x 0.15 = 3.0 gallons per hour is the injection rate.

The calculation by the formula is slightly more accurate than reading the values from figure 1. However, the use of figure 1 is sufficiently accurate for all practical purposes.

INJECTION METHODS

The method of fertilizer injection into an irrigation system depends on the type of pump and distribution system. The injection equipment can differ for a shallow well pump and a deep well turbine pump. With the shallow well pump, the suction line has a negative pressure available to draw the fertilizer solution from an open tank. With the deep well turbine pump, there is no suction line available where the pressure is less than atmospheric. Hence, with a deep well turbine the liquid fertilizer must be injected into the discharge pipe line at a pressure greater than the discharge pressure of the pump.

Suction Intake

With a shallow well pump and set-type distribution equipment, a rather minimum investment needs to be made in equipment for injecting a fertilizer solution. Granular fertilizer can be dissolved in an open tank and drawn into the system through the suction side of the pump. A small pipe tapped into the discharge line of the system provides for filling the container and mixing the granular fertilizer so it will dissolve with the water. The equipment necessary for this type of injection is pipe or hose and valves together with an open container such as a 55-gallon barrel to contain the fertilizer solution. The suction line from the fertilizer container to the irrigation system suction line should be at least ¾-inch diameter. This equipment is shown in figure 2.

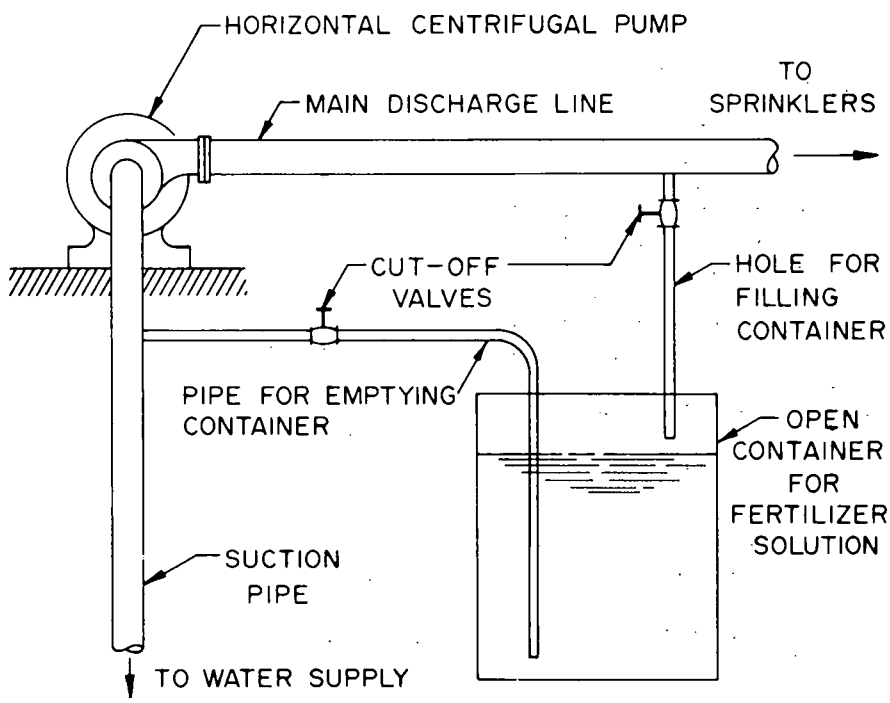

Figure 2. Suction intake fertilizer injection

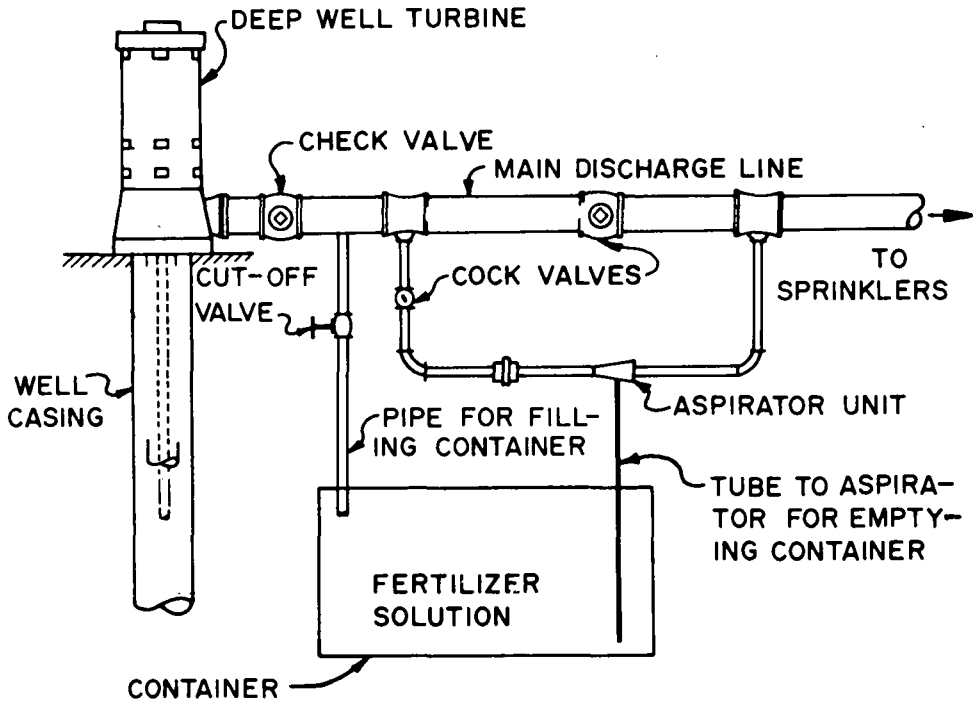

Figure 3. Aspirator-type fertilizer injector

Aspirator Pump

Another arrangement for injecting fertilizer into an irrigation system is with an aspirator type unit shown in figure 3. Three openings are made in the main discharge line. One opening is to provide a pipe for filling the container which will hold the fertilizer solution. The other two openings are for a pressure line which contains the aspirator unit. On the main discharge line a valve is located between the two openings. This valve is partially closed to build up a friction loss and to force water flow through the small pipe which contains the aspirator — it operates on much the same principle as a perfume bottle atomizer. A liquid at high speed flowing through the aspirator unit causes a decrease in pressure below atmospheric pressure. In the unit shown in figure 3, this decrease in pressure below atmospheric pressure causes the fertilizer solution to be drawn into the aspirator and to be injected into the irrigation system.

When the injection of fertilizer into the irrigation system is finished, the valve on the main line is moved to the open position so that the friction loss does not continue in the line. The friction loss which is used by the aspirator unit will decrease the pressure to the irrigation sprinkler. Thus, less fuel is required when the fertilizer is injected as quickly as possible and the valve then opened to reduce the system's friction loss. This practice may not result in the best distribution of fertilizer through the root zone, however.

Venturi Injector

Another type unit which uses a similar principle to inject fertilizer into an irrigation system is the venturi-type fertilizer injector. This injector also uses the friction loss principle to cause a change in pressure so that some of the irrigation water flows through the tank (see figure 4), dissolves the granular fertilizer, and carries the solution into the main discharge line. The tank must be strong enough to withstand the operating pressures of the irrigation system. One disadvantage of this type of fertilizer injector is that it requires friction loss to provide a flow of water through the tank and this friction loss is always present in the discharge line. It is possible to install parallel piping around the fertilizer injector so that the flow of water would not pass through the venturi except when fertilizer is being injected into the system.

With the venturi-type fertilizer injector, the irrigation pump can be either the shallow well or the deep well type. However, the distribution system must be of the set-type since the concentration of fertilizer being injected into the irrigation water is not constant.

Auxiliary Pumps

If the irrigation pump is of the deep well type, then a suction line will not be available to empty the container with the fertilizer solution. Figure 5 shows two small openings in the main discharge line, one con-

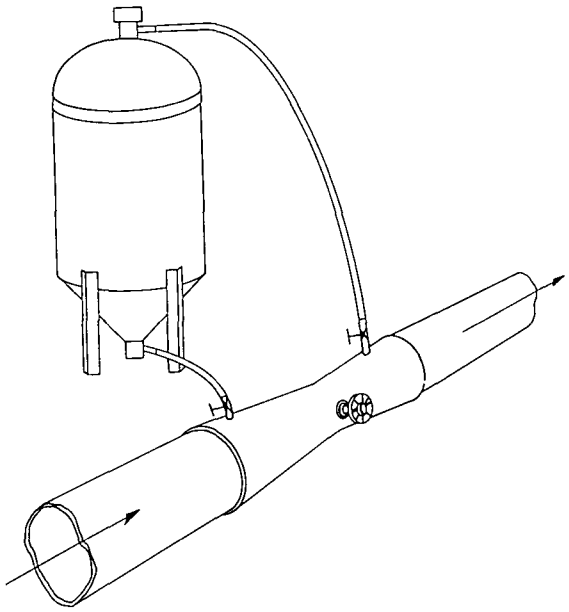

Figure 4. Venturi-type fertilizer injector

taining the pipe for filling the container with water to dissolve the granular fertilizer and the other containing the pipe through which the fertilizer solution is injected into the main discharge line. Since the main discharge line is under pressure, it will be necessary to have an auxiliary pump which is motor driven. This pump must develop more pressure than the irrigation pump.

With a set-type irrigation system, the flow rate of fertilizer mixture into the irrigation system is not critical and, as mentioned before, the concentration of the fertilizer solution may vary if the distribution system is the set-type.

With continuous-move irrigation systems, the pressure requirements are nearly constant during the operation of the equipment. The water flow to the irrigation system also remains constant. The injection pump must deliver the fertilizer solution into the discharge pipe at a constant rate and at a pressure greater than that of the water in the pipe.

Injection pumps usually are the constant displacement type. This means that the amount of liquid the pump discharges does not vary with respect to the pressure against which it pumps. If the pressure in the discharge line of the irrigation system increases, a constant displacement injection pump would still inject the fertilizer solution at the same rate.

The most common type of fertilizer injection pump in use is the piston type. The rate of injection can be varied by the length of travel of the piston. To inject a greater quantity of fertilizer solution, the length of the piston stroke is increased. The pump construction materials must be durable and resistant to the highly corrosive fertilizer solution.

There are different methods available to drive the fertilizer injectors. Figure 6 shows a water motor-powered fertilizer injector. This motor uses water from the main line pipe to operate a hydraulic motor which in turn drives the injection pump. The water which drives the motor goes to waste. However, the quantity of water required to drive this motor is usually from 5 to 6 gallons per minute: a rather insignificant amount compared with the total flow of the irrigation system.

Another method of driving an injection pump is shown in figure 7. A belt around the drive shaft of the power unit and the pulley of the injection pump drives the unit. A field installation of the same type unit is shown in figure 8.

The speed is changed in the gear box and the rotary motion is changed to an oscillating motion to drive the piston. The rate of injection of the fertilizer solution into the sprinkler system depends on the speed of the drive shaft and the length of the piston stroke. This length can be adjusted according to the demands of the system as in figure 9.

The fertilizer injector pump should have a screen on the suction line to filter foreign particles out of the fertilizer being applied. Since the tolerances required to develop the high pressures are so small, abrasive particles in the solution could cause excessive wear on the injection pump.

A spring loaded two-way check valve will prevent gravity flow of the fertilizer solution into the irrigation pipe when the system is off. The check valve will also prevent irrigation water from flowing back through the injection unit into the fertilizer tank when the injector is not in operation.

When the injection pump is powered by a belt from the drive shaft to the irrigation pump, there is no danger of loading the irrigation pipe with fertilizer when the irrigation pump stops.

The same pump type shown in figures 7 and 8 can be driven by auxiliary power units, such as small gasoline engines, or electric motors as shown in figure 9. This type injecting pump may be used with the set-type system, but it is absolutely necessary for the continuous-move systems.

However, when the injection pump is powered by an auxiliary motor, provision must be made to shut off the injection pump if the irrigation pump is shut off. Shutdown of the irrigation pump may be caused by a safety control. Whenever the irrigation power unit is shut off, the power to the injection pump must also be shut off.

If there is danger that the injection pump would run out of liquid and operation without fluid would damage it, then safety controls should be installed to shut off the power. This might be a liquid level device or a pressure safety control switch.

There are other types of fertilizer injecting pumps on the market, but the main points to remember are that the type of pump to use depends on the type of irrigation pump and distribution system.

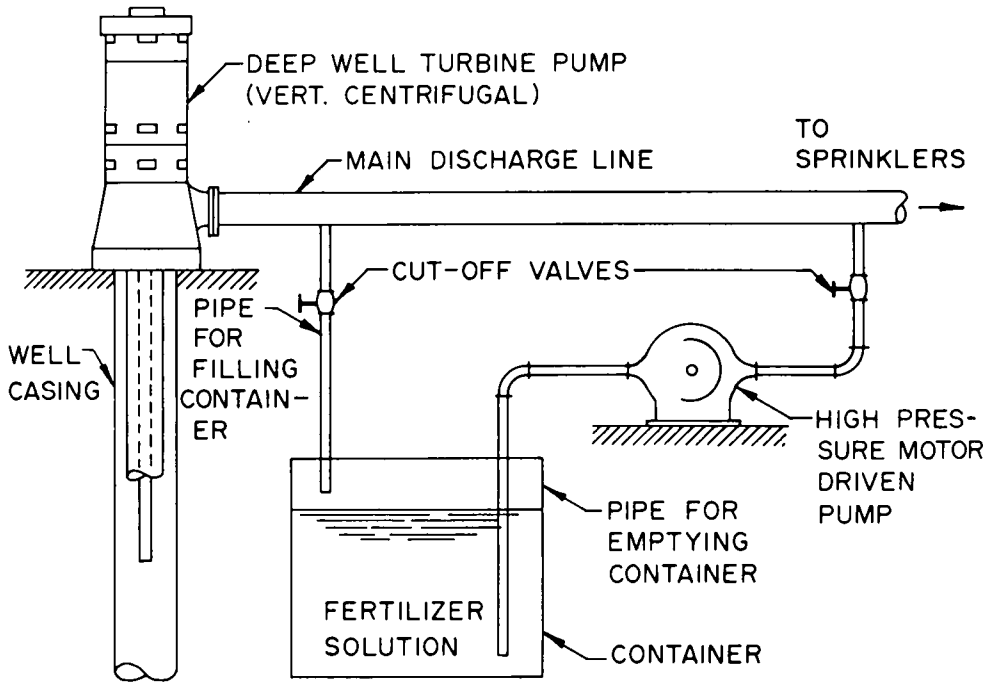

Figure 5. Auxiliary pump for granular fertilizer injection

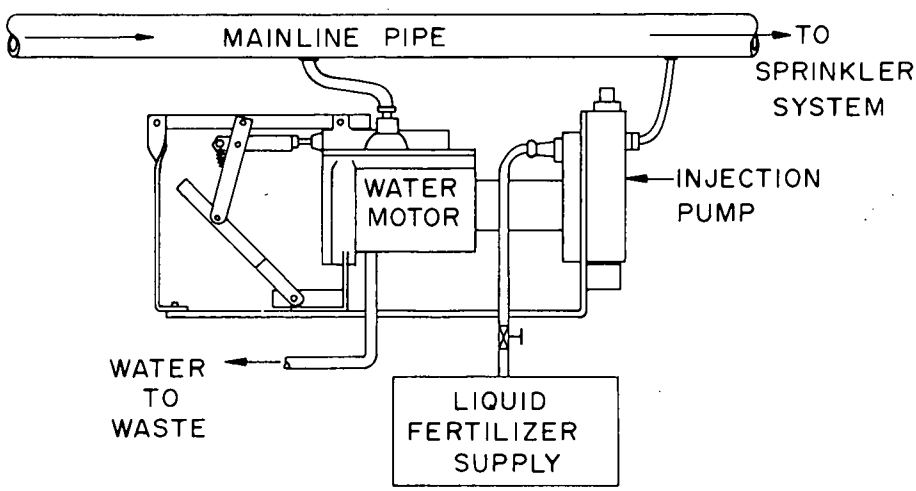

Figure 6. Water motor-powered injection pump

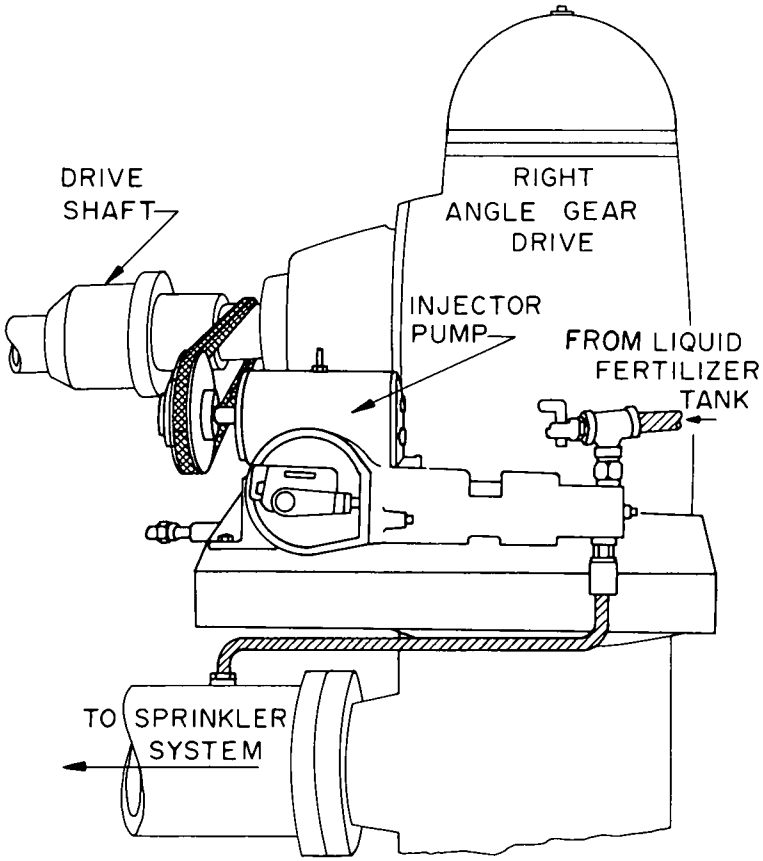

Figure 7. Drive shaft-powered injection pump

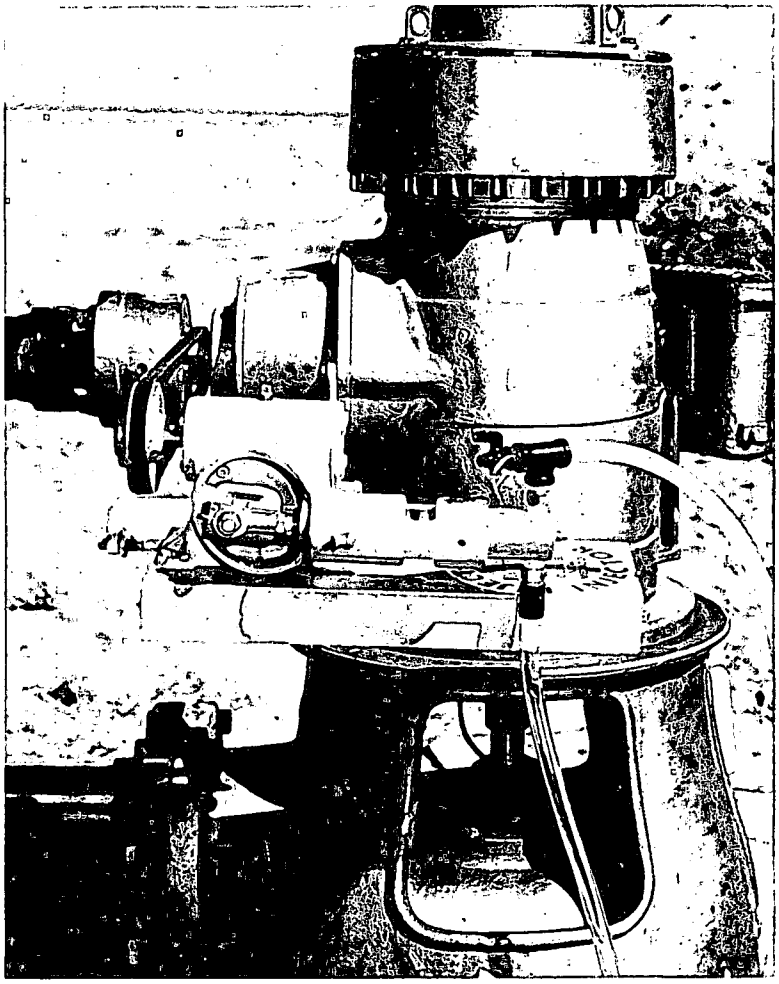

Figure 8. Field installation of V-belt drive injection unit
(photo courtesy Inject-o-Meter Manufacturing Company)

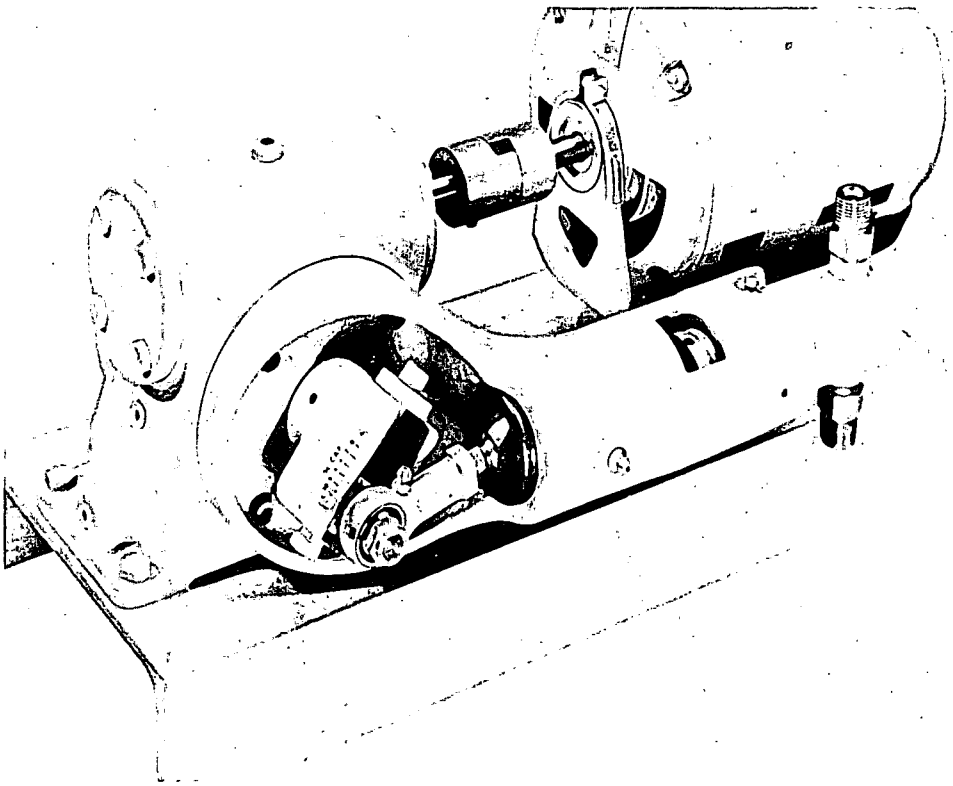

Figure 9. Injection pump, gear box, and motor assembly with graduations on eccentric for indicating stroke length
(photo courtesy Inject-o-Meter Manufacturing Company)

Costs

The cost of the fertilizer injection system will range from less than $50 to more than $450, depending on the type of equipment required. Cost of a shallow well pump with a set-type irrigation distribution system will include some piping and a container to mix the fertilizer solution. If the irrigation system is a continuous-move type and an auxiliary power unit is required for the fertilizer injection pump, then cost may exceed $450.

Return

The return on the investment in the fertilizer injection pump may be realized in two ways. Spoon feeding the crop should increase the total yield and profits. Also, by repeatedly injecting fertilizer in small amounts as the plant needs it, less total nutrients should be required for a given crop production. These two considerations should make the cost of a fertilizer injecting unit a wise investment.

Note Carefully

There have been instances where fertilizer has been dumped directly into a well or water supply. This practice should be condemned and is absolutely forbidden by State of Minnesota law. This practice can contribute to the pollution of underground water supplies and will not be condoned by the Minnesota Pollution Control Agency. The fact that this practice is an extremely poor method of injecting fertilizer elements into irrigation water is completely over-shadowed by the fact that it may pollute underground water supplies.

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M-150

Safety Controls for Irrigation Power Units

Roger E. Machmeier, extension agricultural engineer

March 1970

Modern irrigation systems are designed to save labor and to operate unattended. Sprinkler systems such as the center-pivot self-propelled type operate continuously on a 24-hour per day basis. Other types of sprinkler systems may remain unattended for as long as 12 hours. An irrigation system is a large investment, with prices ranging up to $30,000 for a 140-acre, center-pivot unit.

The power unit and pump might be considered the heart of the system. An irrigation pump places a constant horsepower demand on a power unit. The electric, diesel, or spark ignition power unit must be selected to deliver the required horsepower on a continuous basis. Horsepower demands are usually high. For example, to pump 900 gallons per minute at a discharge pressure of 75 pounds per square inch from a well with a 50-foot lift requires 75 horsepower (assuming 65 per cent pump efficiency).

If the power unit is rated on a continuous basis, then a 75 horsepower unit may be used. However, if the power unit is rated for intermittent operation, then the engine must be rated at considerably more than 75 horsepower to be able to produce 75 horsepower on a continuous basis. Check with your equipment supplier to be sure that the power unit is large enough to do the job. Further information on horsepower requirements is available through your Agricultural Agent or your Extension Agricultural Engineer.

Occasional reports are received of diesel and gasoline engines failing, and of electric motors overheating and being destroyed. A fan belt break, oil line rupture, coolant loss, or loss of pump prime can cause excessive damage to pump and power units in a very short time. In addition to the cost of repairs for the equipment, the down time of the irrigation system, which deprives the crop of water, may be even more costly. It is reported that cooling and lubrication system failures account for nearly 90 per cent of all engine damage.

However, there is absolutely no reason for power units to be destroyed or damaged. Properly installed and functioning safety controls will shut down equipment the instant engine temperature becomes critical, oil pressure fails, or irrigation system water pressure drops. Safety controls can make the difference between major damage and repairs, and minor maintenance.

The investment in safety switches is a very minor item when compared with the total investment in irrigation equipment and in the crop. A complete set of safety controls usually costs 50 dollars or less. Compare this cost with a major overhaul or replacement of the power unit or with a decrease in yield because the irrigation schedule was interrupted and the crop received inadequate moisture.

The safety controls usually have gauges which simply replace the gauges normally found on equipment. Oil pressure, coolant temperature, and pump pressure safety controls replace nonprotective gauges. Installation is relatively simple and inexpensive and should be considered a necessary part of any irrigation system.

Safety controls should be installed on tractors as well as stationary engines used to power irrigation pumps. Any power unit that is used at any time to drive an irrigation pump should be equipped with proper safety controls.

With an electric motor for power, controls are required to prevent excessive current draw and motor overheating. A safety control should be used to stop the motor in case of the loss of irrigation system water pressure.

Types of Safety Switches

Three major types of safety switches are used to protect battery ignition engines on irrigation pumps. They relate to engine oil pressure, engine water temperature, and irrigation pump pressure. For air-cooled engines, an oil temperature safety switch is used rather than the water temperature switch.

With the loss of oil pressure, an engine can be damaged in a very short time by improper lubrication. The oil pressure safety switch may have an adjustable contact point which can be set for the minimum allowable oil pressure.

The water pump pressure safety switch shuts down the power unit if the pump loses its prime. If the power unit did not have this protection, it would be liable to "run away" if the pump lost prime.

If an irrigation pipe coupling or gasket fails and the pump continues to operate, the decreased pressure and the resulting increased discharge may overload the power unit. The characteristic curve of a centrifugal pump is such that, for a given RPM, the horsepower requirements increase with a drop in discharge pressure. This increased load on a power unit not properly protected by safety devices can cause it to burn up.

The engine water temperature safety switch is necessary to prevent the unit from running too hot. In some instances, a change in wind direction may prevent adequate air circulation to the radiator. Irrigation pumps are often located near streams or lakes where air circulation may be restricted by vegetation. With little or no wind and a very warm day, the unprotected engine can easily overheat.

If the fan belt breaks, the engine overheats immediately. Thus, any of a number of factors can cause the engine to overheat and require that the pumping unit be shut down.

Air cooled engines develop excessive crankcase oil temperatures before they burn up. Thus, a safety switch is necessary to sense oil temperature and to shut down the unit if the oil temperature reaches a preset maximum.

The needles on engine oil pressure and pump water pressure safety switches touch insulated contacts to stop the engine when readings are low (see figure 1). The needles also touch these contacts when the engine is stopped.

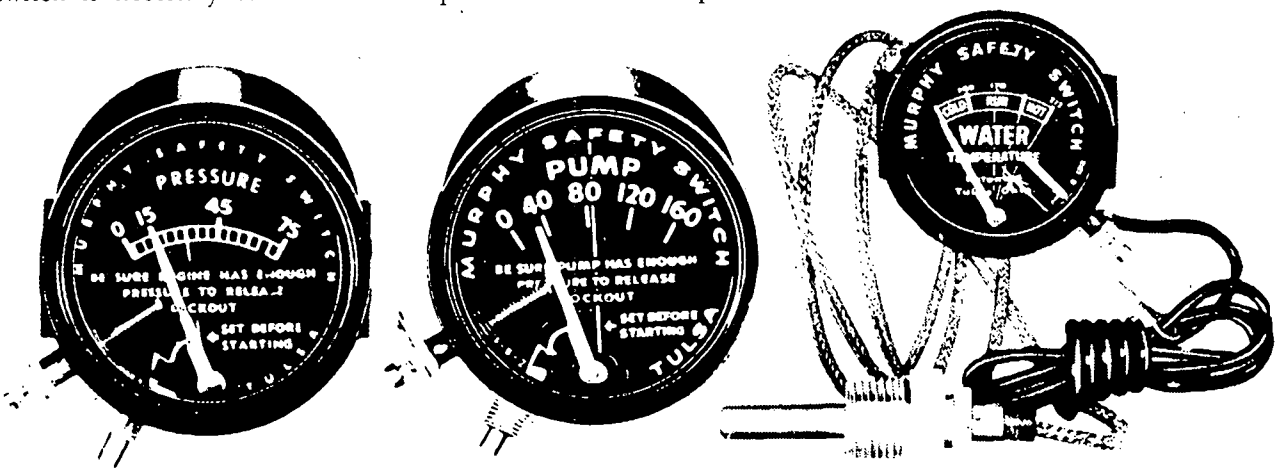
A lock-out device may be used to override this contact while the engine is being started and until water pressure is built up in the irrigation system. The lock-out device releases automatically as soon as the gauge needle moves.

A manual on-off switch may be installed in the circuit to disconnect the safety switches during starting. However, the automatic feature is more desirable since the operator is not required to remember that the safety switches must be turned on.

The needle of the engine water temperature or oil temperature safety switch does not make contact until the temperature reaches a preset maximum. Thus, this type of safety switch may remain in the circuit without a lock-out device or an on-off switch. If the engine water or oil temperature reaches the preset maximum during operation, the grounded needle makes contact with the insulated terminal and completes the circuit to stop the engine.

The engine oil pressure, pump water pressure, and engine water temperature (or oil temperature in the case of air-cooled) are all necessary to adequately protect an engine against damage.

In a typical installation, several safety switches are connected in parallel. Any one of them can stop the power unit.



Illustrations courtesy of Frank W. Murphy, Manufacturer, Inc., Tulsa, Oklahoma

Figure 1. Safety switches designed to monitor engine oil pressure, irrigation pump pressure, and engine water temperature.

Types of Power Units

BATTERY IGNITION

The safety switches for a battery ignition engine are connected into a circuit with a magnetic switch as shown in figure 2.

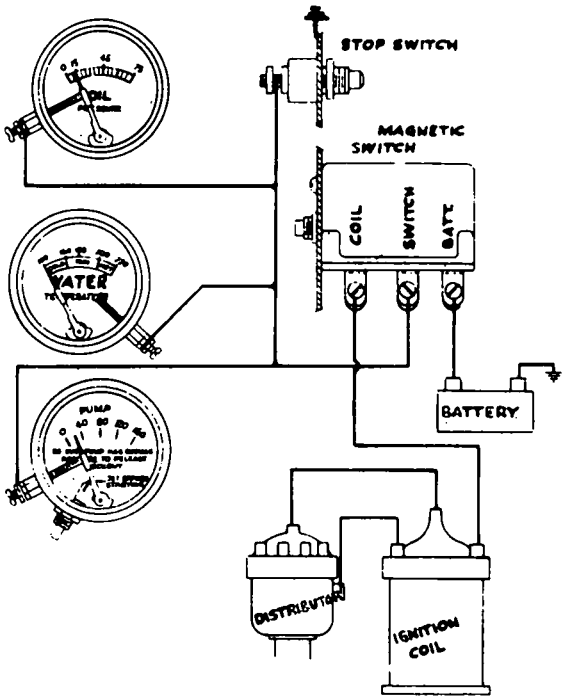


Figure 2. Wiring diagram for battery ignition power units.

In each of the safety switches, the needle is grounded. When the needle makes contact with the other terminal of the safety switch, current flows through the magnetic switch to open the ignition circuit.

The safety control circuit with magnetic switch is shown in figure 3. The ignition coil is connected to the COIL terminal switch and the safety switch is connected to the SWITCH terminal. The BATTERY terminal connects to the ignition switch or ammeter. When the grounded pointer (C) of the safety switch touches the insulated contact (J), the circuit is completed through the electromagnet (F). The electromagnet (F) pulls the armature (D) which releases the spring-loaded swinging contact latch (B). This action opens the contact points (H) in the ignition coil circuit, and stops the engine. After the magnetic switch operates, the ignition circuit is open and no current can flow to drain the battery. The push-button (A) must be operated manually to reset for starting.

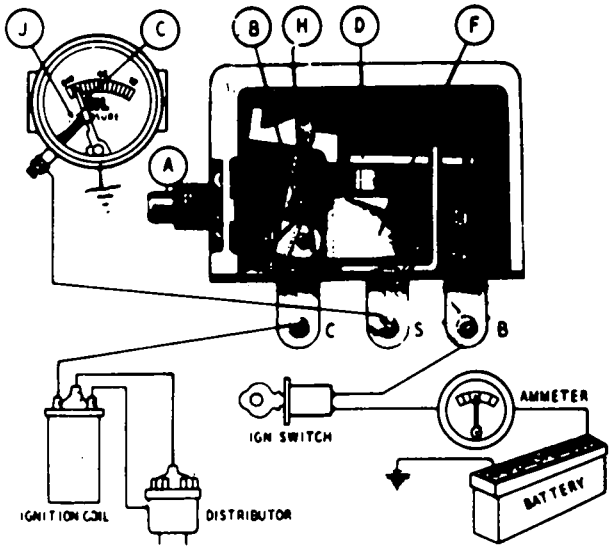


Figure 3. Magnetic switch with control circuit.

MAGNETO IGNITION

The same three types of safety switches necessary for battery ignition engines are required for magneto ignition. They relate to engine oil pressure, engine water temperature (engine oil temperature for air-cooled), and water pump pressure.

The safety switches are connected into a circuit as shown in figure 4.

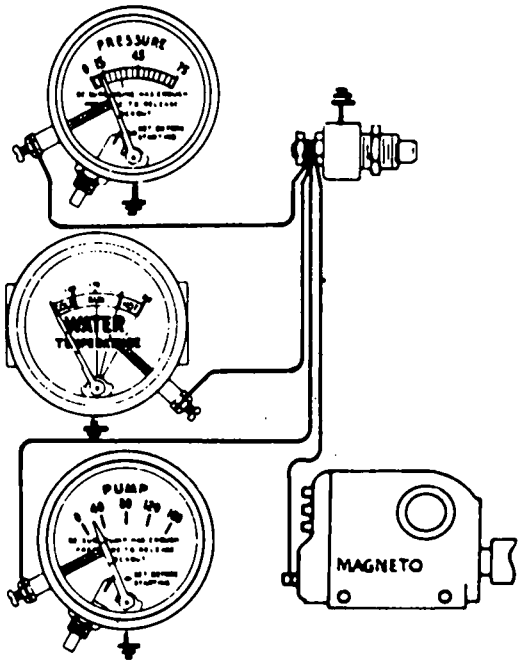


Figure 4. Wiring diagram for magneto ignition power units.

The operation of the respective switches is the same as previously described. To start the engine, a lock-out device must be provided for the engine oil pressure and the pump water pressure switches.

With single magneto ignition, it is not necessary in most instances to use a magnetic switch for shutdown. The grounding post of the magneto will perform satisfactorily.

However, if carbon deposits occur on the cylinder heads a post-ignition cycle can occur and the engine will continue to run or "diesel." Ignition will take place due to the presence of fuel and heat in the carbon.

The magnetic switch is suitable for single magneto engines (see figure 5(a)) and would eliminate the possibility of the engine continuing to run without ignition. However, on irrigation power units which are heavily loaded, the magneto ground post will usually be satisfactory to accomplish shutdown.

In the case where there are multiple magnetos on an engine, a magnetic snap switch is needed. Figure 5(a) shows the connection of the magnetic switch to an oil pressure safety switch and Figure 5(b) shows the connections for multiple magnetos.

When the grounded pointer (C) touches the contact (J), the circuit is completed through the electromagnet (F) to the primary terminal on the magneto. The magneto current energizes the coil (F) and pulls the armature latch (D) down releasing the spring-loaded swinging latch (B) to make contact with the grounded contact (E). The magneto is permanently grounded until manually reset with the button (A). For engines with multiple magnetos, the magnetic snap switches are manufactured with added magneto terminals.

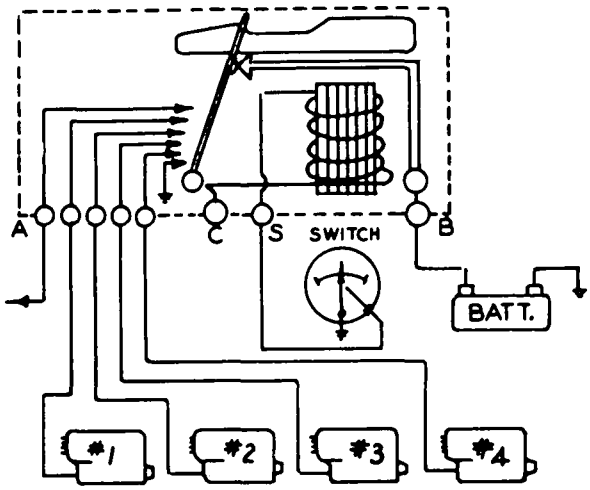


Figure 5b. Multiple magneto ignition system.

DIESEL

For diesel engines, the safety switches are connected into a circuit which shuts off the fuel supply. (See figure 6.)

The magnetic switch is used to hold open a normally-closed solenoid fuel valve during normal operation. The diesel engine must have a battery and generator for this type of circuit. The operation of the circuit is the same as with a distributor ignition system except that the magnetic snap switch operates the circuit to the solenoid valve. When a safety switch operates, the circuit to the solenoid valve is opened. This closes the solenoid valve and stops the fuel supply to the injectors.

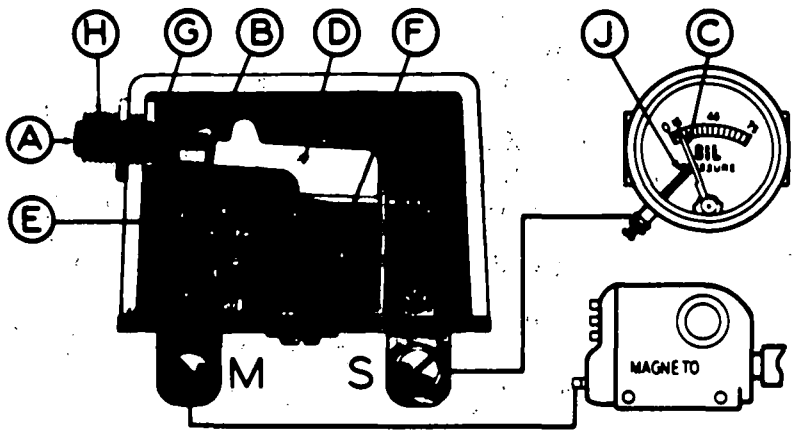


Figure 5a. Magnetic switch for magneto ignition engines.

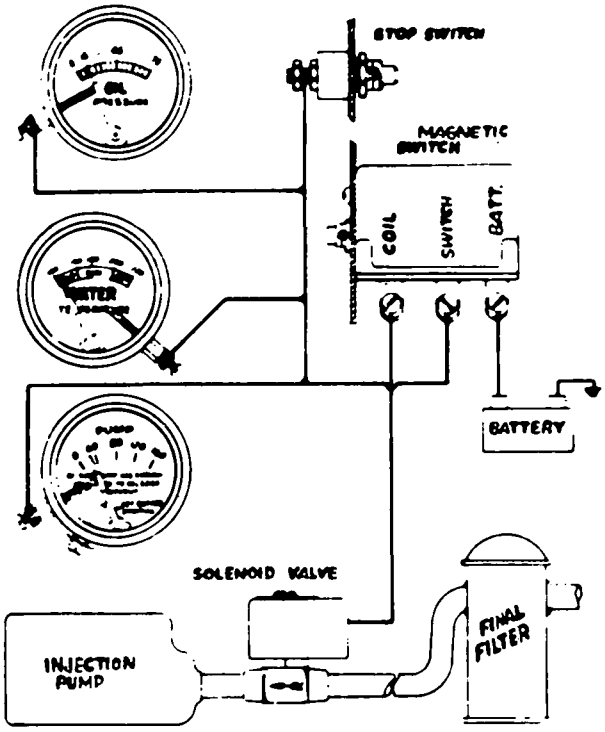


Figure 6. Wiring diagram for diesel power units.

ELECTRIC

When an electric motor is used as an irrigation power unit, the pump water pressure safety switch is used. This stops the electric motor if a pipeline breaks or the pump loses prime. In addition, the electric control panel should have overload protection which will stop the motor in the event of excessive current draw.

The wiring of the water pressure safety control and the overload protection should be performed only by qualified personnel. The three-phase power normally used for large electric motors may be connected in a delta or wye system. It is essential that the safety control and overload protection cut out enough phases to stop the motor.

With properly connected and operating safety controls no electric motor should ever burn up because of overload.

Audio-Visual Alarms

An irrigation system should be designed to supply all of the water required for crop production. During peak moisture use periods, it may be necessary to run the irrigation system continuously. Thus, the operator should be aware of any engine shut down so the trouble can be corrected and the irrigation system returned to operation. A warning light, siren, whistle, or horn can easily be added to the safety control circuit to immediately alert the operator of a system failure.

Other Controls

An engine coolant level switch can provide an added degree of protection. If a bottom radiator hose should break, no coolant water would surround the sensing bulb of the temperature safety control and the temperature switch would not give a proper indication of the engine temperature. The coolant level safety switch would then act to shut down the power unit. The coolant level safety switch should be used together with the temperature safety switch and not replace it.

An engine oil level safety switch will provide protection in addition to the oil pressure safety switch. If the oil pump of an engine is in good condition, the oil pressure may remain relatively high even though the engine might be low on oil. The oil temperature would likely increase and at approximately 230° F. oil has a tendency to lose its lubricating properties. This condition could result in bearing failure.

The engine oil level safety switch has a high contact position as well as a low contact. On diesel engines where leaking injectors are a problem the high contact is useful. Also, water or other foreign liquids could find their way into the crankcase and cause problems.

In addition to the controls described above, some types of irrigation distribution systems have special safety controls as standard equipment. For example, a center-pivot self-propelled unit has a safety control system which will shut down the power unit if misalignment occurs. This safety system is necessary to prevent damage to the towers and pipeline. All of the safety controls described are necessary to operate together and to protect the irrigation system.

Summary

An irrigation system which operates unattended must have adequate and properly operating safety controls. There is no reason for any power unit to be damaged when, for a modest investment, an irrigator can protect his system against such a possibility.

Irrigation Power Unit Selection

CIRCULAR
AE-88
(REVISED)

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I. GENERAL

Any device used to drive an irrigation pump is called an irrigation power unit. Irrigation power units commonly used include electric motors, internal combustion engines, and farm tractors.

An irrigation power unit must fit the irrigation pump requirements if an efficient operation is to be maintained. An engine or motor that is too small cannot provide the power necessary to deliver water at the rate and/or pressure required by the irrigation system. An engine or motor larger than necessary may provide service, but at an excessive initial cost.

The properly designed power unit will meet the requirements of an irrigation system without supporting idle capacity. An irrigation load is constant. Therefore, the power unit chosen must be suitable for continuous duty at the design load. Electric motors are designed and rated for constant loads. An internal combustion engine must either be rated for continuous duty at the design load or derated from some other horsepower rating to a continuous horsepower rating. Either industrial internal combustion engines or electric motors are suitable for irrigation. Farm tractors should not be used for permanent installations because they are not designed for the 24-hour per day continuous loading required for irrigation. If a tractor is to be used on a temporary installation, it should be protected with safety controls to prevent engine damage and operated at less than maximum horsepower.

The power unit selection should be made only after considering the following:

A. The amount of brake horsepower for pumping. This includes the amount of water to be pumped, elevation differences between the source and the delivery point, the operating pressure of the system, friction losses, power unit efficiency, and pump efficiency.
B. Hours of operation per season.
C. Availability and cost of energy or fuel (in case of electricity, availability of three-phase power may influence the selection).
D. Availability of parts and service.
E. Depreciation.
F. Whether portability is desired in the pumping operation.
G. Labor requirements and convenience of operations.
H. Original cost.

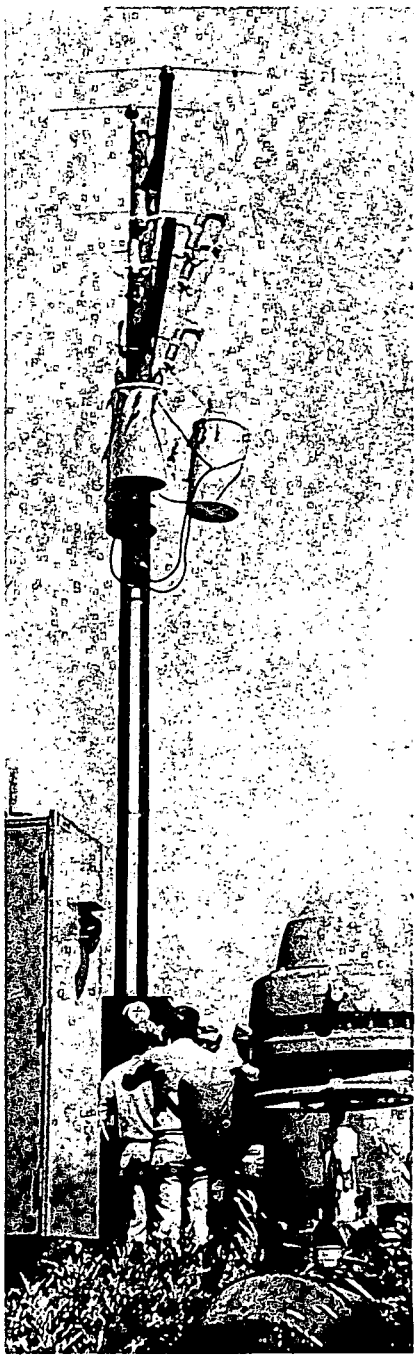
It is highly important to match the engine horsepower to the requirements of the pump. Previously used power units should be carefully checked and evaluated as to condition, available horsepower, and speed. The use of an old, misfit power unit can be more costly from an operating standpoint than the most expensive unit fitted for the job.

II. POWER REQUIREMENTS

The determination of the actual horsepower requirement of the power unit used in driving a pump requires that we know the total dynamic head, the pumping rate, the efficiency of the pump, the drive efficiency, and the type of power unit.

To determine total operating or dynamic head, several separate figures must be added together. By definition Total Dynamic Head = Total Static Head + Pressure Head + Friction Head + Velocity Head (Figure 1).

TOTAL STATIC HEAD is the total vertical distance the pump must lift the water. When pumping from a well, this would be the distance from the drawdown water level in the well to ground level plus the distance the water is lifted from ground level to the discharge point.



PRESSURE HEAD. Sprinklers require pressure to operate. Center pivot systems require a certain pressure at the pivot point to distribute the water properly. Note: The pressure in PSI is normally converted to feet of head for calculation purposes (see Table 1). PSI x 2.31 = Head in Feet of Water.

FRICTION HEAD is the loss due to friction when water flows through pipes. Additional friction loss also occurs when water flows through fittings or valves, around corners, or at increases or decreases in pipe size. Values for these losses are obtained from friction loss tables.

VELOCITY HEAD is the energy given the water to get it into motion. This is a very small amount of energy and is usually negligible when computing losses in an irrigation system.

Table 1. PSI (Pounds Per Square Inch) Versus Head in Feet of Water

psi	Head (Ft)	psi	Head (Ft)	psi	Head (Ft)
0	0	35	80.8	70	162
5	11.5	40	92.4	75	173
10	23.1	45	104	80	185
15	34.6	50	115	85	196
20	46.2	55	127	90	208
25	57.7	60	138	95	219
30	69.3	65	150	100	231

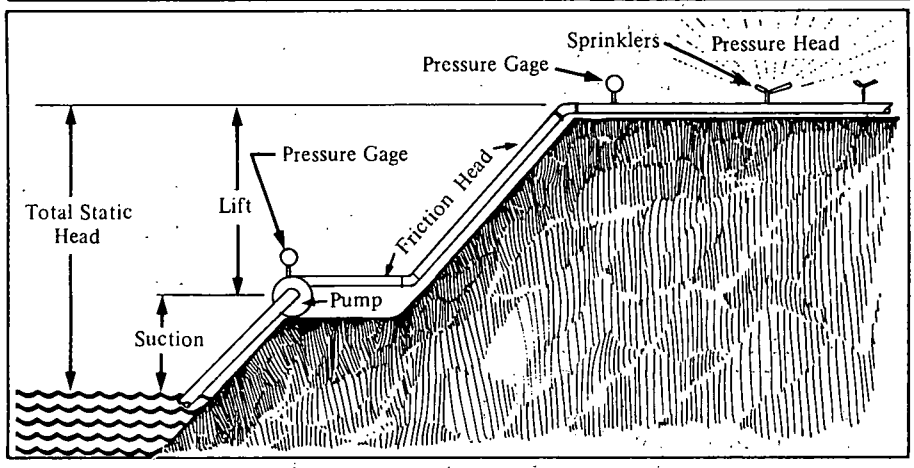


Figure 1. Total dynamic head is the sum of total static head plus friction head plus pressure head. Total dynamic head will equal gauge pressure reading at the pump x 2.31 plus the suction lift. Total dynamic head will also equal gauge pressure reading at the sprinklers x 2.31 plus total static head plus friction head.

The useful work done by a pump is called "water horsepower" (WHP) and is calculated as follows:

$$WHP = \frac{Q \times TDH}{3960}$$

Q = Discharge in GPM (gallons per minute)
TDH = Total dynamic head in feet

Some other formulas which may be used to determine WHP, but use different units of measurement are:

$$WHP = \frac{Q \times TDH}{8.8}$$

WHP = Water Horsepower
Q = Discharge in CFS (cubic feet per second)

$$WHP = \frac{Q \times P}{1714}$$

WHP = Water Horsepower
Q = Discharge in GPM (gallons per minute)
P = Pressure in PSI (pounds per square inch)

The water horsepower represents the power required to operate the pump if the pump and drive were 100 percent efficient. The brake horsepower (BHP) is the actual horsepower requirement at the drive unit connection and takes pump and drive inefficiencies into consideration. The continuous horsepower rating of the power unit must equal this value and is calculated as follows:

$$BHP = \frac{WHP}{\text{Pump Efficiency} \times \text{Drive Eff.}}$$

BHP = Brake Horsepower (continuous horsepower rating of power unit)
WHP = Water Horsepower

The pump efficiency must be obtained from a sales representative and the drive efficiency may be found in Table 2. A well designed irrigation pump should be 70 percent to 80 percent efficient. A figure of 75 percent can normally be used for preliminary planning.

Table 2. Drive Efficiency

Type of Drive	Normal Efficiency
Direct	100%
Flat-Belt (straight)	85%
Flat-Belt (1/4 to 1/2 turn)	75%
V-Belt	95%
Right Angle Gear Head	95%

III. INTERNAL COMBUSTION ENGINES

A. Horsepower Ratings

Fuels for internal combustion engines are gasoline, diesel, propane, and natural gas (Figure 2). Manufacturers have developed performance curves for each of their engines showing horsepower ratings at various speeds for use as a basis in engine selection. These curves are developed in a laboratory under conditions of 60°F temperature, mean sea level elevation, and with a bare engine to produce the most horsepower per unit of engine weight. For field use these curves must be corrected to reflect the power loss caused by the use of accessories, elevation differences, and air temperature. Because of the characteristics of internal combustion

engines, it is also necessary to further correct the horsepower curve to compensate for the continuous loading required in irrigation pumping. Figure 3 shows how a horsepower versus RPM curve is changed after corrections are made for accessories and continuous operation. Actual reductions of bare engine horsepower are shown in Table 3.

Figure 2. Portable diesel power unit connected to a deep well turbine pump through a right angle drive.

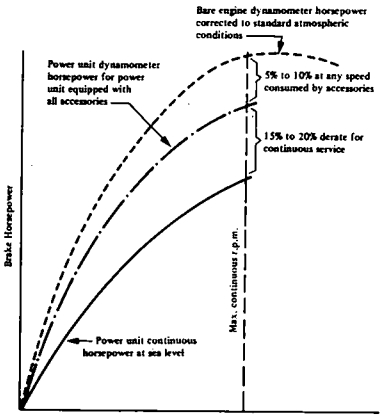


Figure 3. Horsepower vs. r.p.m. curve for internal combustion engines.

Table 3. Corrections to Bare Engine Horsepower Developed under Laboratory Conditions

For each 1,000 feet above sea level deduct	3%
For each 10°F. above 60°F. deduct	1%
For accessories (generator, etc.) deduct	5%
For radiator and fan deduct	5%
For continuous operation deduct	20%

Some manufacturers publish both the dynamometer curve and the continuous brake horsepower curve in their literature. When only one curve is shown, that curve will generally be the horsepower determined by a dynamometer under laboratory conditions.

The best operating load for an internal combustion engine is at or near the continuous brake horsepower curve. Running an engine under much lighter loads usually results in poorer fuel economy for the water delivered, since too much horsepower is used in overcoming engine friction and throttling losses. Running at maximum engine horsepower invites engine trouble as well as excessive fuel consumption.

B. Cooling Jackets

Heat exchangers should meet the size requirements based on engine size and established by the manufacturer.

In some instances, however, heat exchangers may be used on installations in sheltered areas where air movement around the unit is very poor and where the source of water is reasonably warm. This situation will require the use of a larger heat exchanger than normally recommended. Addition of a fan to move hot air away from the engine may increase fuel consumption slightly, but will eliminate safety switch shut downs during extremely hot weather.

IV. ELECTRIC MOTORS

A. General

Electric motors are used on a large portion of North Dakota irrigation systems. If properly installed and protected, electric motors will provide many years of service. Advantages of electric power include relatively long motor life, low maintenance costs, dependability, and ease of control and operation. An electric motor will deliver full power throughout its life and can be operated from no load to full load without damage. Disadvantages of electric motors include constant speed, an electric power supply required at each pumping spot, and normally a yearly minimum power cost.

Always contact your power supplier early when considering irrigation. The required electrical construction takes time.

B. Motor Types

Most large electric motors used for irrigation are squirrel cage induction type, three-phase, 460-volt motors. Pumps may be connected to the motors by direct couplings, right angle drives, or belts. Most common, and best if practical, is a direct coupling. Right angle drives and belt drives are less than 100 percent efficient and so require more energy.

Most electrical motors used on centrifugal pumps will be horizontal shaft (Figure 4). On deep well turbine pumps either a vertical hollow-shaft electric motor (Figure 5) or a horizontal shaft electric motor together with a hollow-shaft right angle drive must be used, Figure 6. The hollow-shaft unit is necessary so the pump impellers can be adjusted.

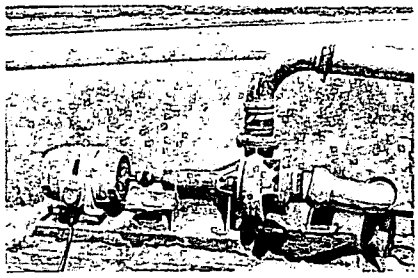


Figure 4. Electric horizontal shaft motor connected to a centrifugal pump.

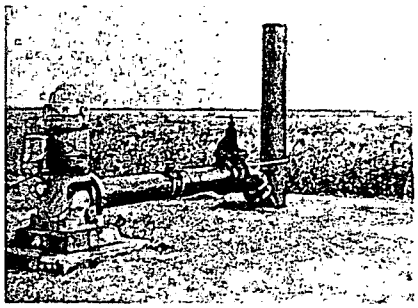


Figure 5. Hollow-shaft electric motor connected to a deep well turbine pump.

The life of an electric motor is normally determined by the life of the motor winding insulation. Electric motor insulation is normally rated for a life of 20,000 hours. For example, Class A insulation has a 20,000-hour life at 105°C; Class B, a 20,000-hour life at 130°C, and Class F, a 20,000-hour life at 165°C. Electric motors for irrigation should be rated for continu-

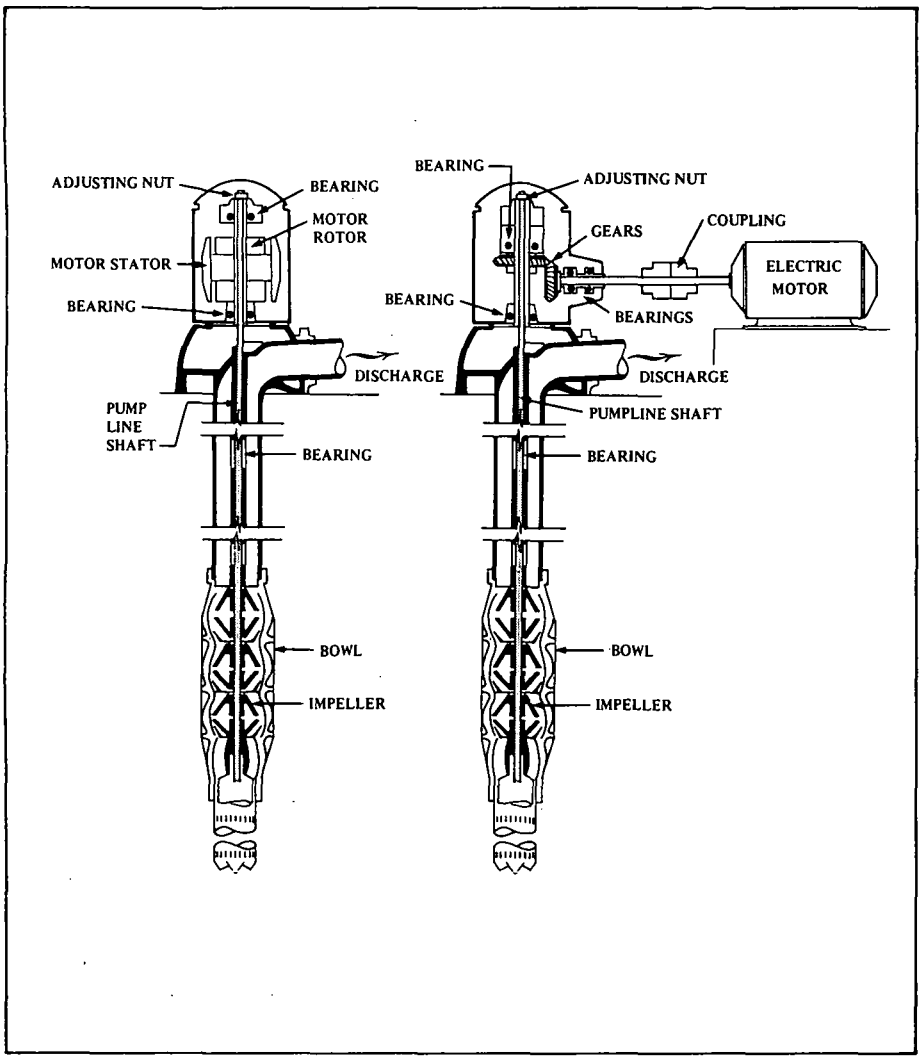


Figure 6. Vertical hollow-shaft electric motor connected to a deep well turbine pump and an electric horizontal shaft motor connected to a right-angle hollow-shaft gear drive and deep well turbine pump. The gear drive unit is also used with internal combustion engines. The hollow-shaft electric motor and gear drive unit have a hollow drive shaft so the pump line shaft extends through them. This is necessary so the impeller adjusting nut is accessible.

ous duty at 40°C or higher maximum ambient temperature and have Class B or better insulation.

Overloading an electric motor causes internal temperatures to rise and drastically shortens expected motor life. Therefore, proper motor sizing is very important. If the calculated total pump load is close to the selected motor size, a service factor of 1.15 on the motor is desirable. A 1.15 service factor means the motor can safely carry a pump load of 115 percent of the rated electric motor horsepower. Unless specified otherwise, most electric motors come with a service factor of 1.0.

C. Irrigation Motors Served by Single-Phase Electric Power Supply

Under certain conditions, an irrigation pump may be best served by a single-phase power supply. Two alternatives are open, either a three-phase electric motor supplied by a phase converter or a special single-phase motor.

Phase converters convert single-phase electric power to three-phase power and may be either the static or rotary type. "Auto-transformer" type static phase converters are applicable to single motor loads where the load on the pump will remain constant. These may be "balanced out" (the phase amperages to the motor made equal) for a particular motor load.

Rotary phase converters are applicable on either single or multiple motor loads. They are desirable for use where a varying motor load may result, such as where a permanently installed pump may draw from a reservoir which varies in height. They also may be used where several motors will be run from one converter. For example, a rotary phase converter may be used to run the tower drive motors on an electric drive center pivot system. These motors are constantly starting and stopping. However, rotary converters need a minimum load for proper operation so one large rotary converter should not be used for both the irrigation pump motor and the pivot drive motors. Under this application the pivot drive motors could not be run unless the large pump motor was also operating.

The proper application of phase converters is critical and should only be done in consultation with the manufacturers, pump supplier, and electric power supplier. Always be certain all three leads to the three-phase motor are protected with the correctly sized overcurrent protection. This will protect the motor from any current imbalance which could result.

Special large single-phase motors which start under reduced current draw are also available in sizes up to 100 horsepower. Because of their design, these special motors may be used on many single-phase lines without adverse effects on other consumers. Again, these are special application type motors and your electric power supplier must be consulted.

D. Motor Starting

During start-up electric motors draw more amperage than they do while running. Depending on location, this momentary high amperage draw may cause a nuisance to other persons receiving their electricity from the same electric distribution line. This high draw causes momentary low voltage and consequential dimming of lights, television picture distortion, etc.

To minimize these starting problems most electric power suppliers require a "reduced-voltage" type of starting panel be used with large electric motors. These "reduced-voltage" starters limit the high amperage draw by the motors during start-up. Four types of reduced-voltage starters are available. The "part-winding" and "wye-delta" type require specially wound motors for their application. The "primary-resistor" type and the "auto-transformer" type may be used with any induction three-phase motor.

E. Special Provisions for Electrical Installations

1. GENERAL

All installations should be in accordance with the National Electric Code, and shall comply with the regulations of the North Dakota State Electrical Board, Bismarck, North Dakota. Motors, electrical enclosures, and other electrical equipment must be effectively grounded by a separate grounding conductor, suitably connected to the power supply grounding system. On new installations, request for wiring inspection must be submitted to the State Electrical Board as required.

2. PROTECTIVE MEASURES

a. Motors shall be supplied through a fused service disconnect. A motor controller (magnetic or manual) and overcurrent protection shall be used.

b. Overcurrent protection for single-phase motors should be of "single-heater" type with the overcurrent unit in the ungrounded conductor. For three-phase motors use the "three-heater" type to provide overcurrent protection in each of the leads to the motor windings. Rating of the overcurrent protection devices should not exceed 115 percent of the motor nameplate amperage. "Ambient temperature compensated" overload protectors may be used to offset the effect of sunshine on control enclosures.

c. Inherent overload protection devices which consist of temperature sensing elements buried in the motor windings are highly recommended, but should not be used in lieu of overcurrent protection described above unless the motor manufacturer fully guarantees the motor against locked-rotor and overload burnout with only the temperature sensing element protection.

3. MOTOR ENCLOSURES

a. Motors should be drip-proof type and if operated with the shaft vertical, be designed to be drip-proof in this position unless protected from the weather by other suitable enclosures.

b. Rodent screens should be installed, either at the factory, or in the field at time of motor installation.

4. SECONDARY LIGHTNING ARRESTORS

a. Secondary lightning arrestors should be installed, and connected from ground to each ungrounded conductor in the supply, on the secondary side of the transformer, but ahead of the service disconnecting means.

V. SAFETY CONTROLS

Safety devices and procedures for protecting the pump and power plant equipment from damage from natural causes, sudden loss of water or power, and errors by operating personnel should be included with every sprinkler system.

Pumping power plants should be equipped with safety devices that shut off the electric motor or engine when there is a break in the suction on centrifugal pumps, or a loss of pressure in the main pipeline. Pumps having water lubricated bearings will be damaged by prolonged operation without water.

Engines used to power sprinkler system pumps should be equipped with safety devices that stop the engine before damage occurs from overload, run-away if pump becomes disconnected or loses its prime, loss of oil pressure, or overheating.

A ratchet coupling should be used between turbine pumps and electric motors or engines to prevent rotation of the power plants on high head sprinkler systems should there be a power failure while these systems are in operation.

Automatic valves that permit pumps to be started or stopped without water damage to high head mainline pipes due to water hammer or surge should be installed as a safety feature.

VI. SAMPLE CALCULATIONS OF FUEL CONSUMPTION AND COST OF OPERATIONS

The actual cost of operating an irrigation power plant depends on the fuel or electricity price and will vary throughout the state. Calculation of the operating cost requires the determination of the water horsepower (WHP) requirements and the total number of hours pumped during the year. Hours of operation depend on the pumping rate, acres irrigated, and the amount of water to be added per acre.

As an example, assume a 132-acre center pivot system, requiring 800 gallons per minute at a head of 250 feet. The crop is alfalfa in an area that gets 10 inches of growing season rainfall. Calculate the total energy consumption for both diesel and electricity.

A. From the formula:

$$\frac{800\ (\text{gpm}) \times 250\ (\text{feet})}{3960} = 50.5\ \text{WHP}$$

B. From Table 5 we should get 11 WHP-hours per gallon of diesel fuel or .88 WHP-hours per KWH for electricity.

$$\frac{50.5 \text{ WHP}}{11 \text{ WHP-hours/gallon}} = 4.6 \text{ gallons diesel fuel/hour}$$

$$\frac{50.5 \text{ WHP}}{.88 \text{ WHP-hours/KWH}} = 63.1 \text{ KWH/hour}$$

C. From Table 4 we get an average water requirement for alfalfa of 23 inches.

$$\frac{23\text{" (total water requirement)} - 10\text{" (growing season rainfall)}}{.8 \text{ (efficiency of irrigation application)}} = 16\text{" gross irrigation water to be applied}$$

D. 450 gpm = 1 acre inch per hour (Table 7)

$$\frac{800 \text{ gpm}}{450 \text{ gpm/acre inch/hour}} = 1.72 \text{ acre inch/hour}$$

E. $\frac{132 \text{ acres} \times 16 \text{ (inches of water)}}{1.72 \text{ acre inch/hour}} = 1228$ hours of operation per season

F. 1228 hours x 4.8 gallons of diesel/hour = 5894 gallons of fuel per season

1228 hours x 63.1 KWH/hour = 77,487 KWH per season

VII. ACTUAL POWER REQUIREMENT

After a pump and power unit have been installed and are running an estimation of the actual power requirement can be made if the fuel consumption is known. Table 6 gives average fuel efficiencies for power units based on brake horsepower hours per gallon or KWH. Note that this is different than Table 5 which gives fuel efficiency based on water horsepower. The difference between water horsepower and brake horsepower is pump and drive efficiencies.

To determine horsepower output from the power unit the following formula is used:

BHP = FC x FE
BHP = Brake horsepower
FC = Fuel consumption
FE = Fuel efficiency (Table 6)

For example, a diesel power unit is using 5 gallons per hour of fuel, what is the horsepower requirement?

73.4 BHP = 5 gal/hr x 14.67 hp-hr/gal

An electric motor is consuming 64 KWH per hour.

74.9 BHP = 64 KWH/hr x 1.17 hp-hr/KWH

The electric consumption may be determined by checking the electric meter. On meters which record electrical demand the pointer will indicate consumption in KWH per hour. On electric meters without a demand pointer the electrical consumption can be determined by counting revolutions of the disk and multiplying that by the K_h factor of the meter. The K_h factor indicates how many watts of electricity are consumed each time the disk revolves. To determine KWH/hour energy consumption, use the following formula:

$$EC = \frac{20 \times K_h \times \text{revolutions of disk in 3 minutes}}{1000 \text{ watts/KW}}$$

For example, an electric meter has a K_h factor of 55 and makes 58 revolutions in 3 minutes.

$$63.8 \text{ KWH/HR} = \frac{20 \times 55 \text{ watts/rev} \times 58 \text{ rev}}{1000}$$

Table 4. Annual Water Requirements for Various Irrigated Crops in North Dakota*

Crop	Water Requirements (inches)
Alfalfa	22 - 24
Corn	18 - 19.5
Wheat	14.5 - 16
Potatoes	16 - 18
Sugar Beets	20 - 22

* *To determine the irrigation requirement subtract out the growing season precipitation and divide the remainder by 0.8 (the application efficiency for the irrigation water).*

Table 6. Average Fuel Efficiency of Power Units

Energy Source	Brake Horsepower-Hours Performance in
Diesel	14.67 HP-HR/GAL
Gasoline	11.33 HP-HR/GAL
Propane	9.33 HP-HR/GAL
Electricity	1.17 HP-HR/GAL

Table 7. Irrigation Water Calculation

1 Acre = 43,560 square feet
1 Cubic Foot = 7.5 gallons
1 AC-IN (acre inch) of water = 27,000 gallons
1 AC-In per Hour = 450 GPM (gallons per minute)

Table 5. Average Fuel Efficiency of Irrigation Power Units

Energy Source	Performance in Water Horsepower-Hours (hours per gallon of fuel for various type drives based on 75 percent pump efficiency)			
	Direct	Right Angle or V-Belt	Flat Belt (straight)	Flat Belt (1/4 or 1/2 turn)
Diesel	11.0 WHP-HR/GAL	10.5 WHP-HR/GAL	9.7 WHP-HR/GAL	8.3 WHP-HR/GAL
Gasoline	8.5 WHP-HR/GAL	8.0 WHP-HR/GAL	7.5 WHP-HR/GAL	6.4 WHP-HR/GAL
Propane	7.0 WHP-HR/GAL	6.6 WHP-HR/GAL	6.1 WHP-HR/GAL	5.3 WHP-HR/GAL
Electricity	0.88 WHP-HR/KWH	0.84 WHP-HR/KWH	0.78 WHP-HR/KWH	0.66 WHP-HR/KWH

AUGUST 1975

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IRRIGATION PUMPS

CIRCULAR
AE-89

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Most irrigation systems require a pump for operation. This pump must be tailored to the individual requirements of a particular water source, water transmission and distribution system.

Before the selection of any pump can take place, a careful and complete inventory of conditions under which that pump will operate must take place. That inventory must include:

1. Source of water
2. Pumping rate
3. Total dynamic suction head
   A. Vertical suction lift
   B. Length and size of suction pipe
   C. Number and kinds of bends
   D. Foot valve and strainer
4. Total discharge head
   A. Vertical lift
   B. Size and length of pipe
   C. Number and kinds of bends
   D. Head required at delivery point (sprinkler system)

Several different types of pumps are available. Which pump to use will depend on the conditions under which it will operate. Pumps most commonly used for irrigation include centrifugal, deep well turbine, submersible and propeller pumps. Centrifugal pumps operate under a wide range of output conditions, however, they normally can lift water only 10 to 20 feet on the suction side of the pump. Deep well turbine pumps are best suited for wells. Submersible pumps are used for wells, but usually in smaller horsepower sizes. Propeller pumps deliver large amounts of water at low heads and their use is limited to gravity irrigation or drainage where large streams will be lifted short distances.

CENTRIFUGAL PUMPS

There are two types of centrifugal pumps, the horizontal centrifugal and the vertical centrifugal. The horizontal centrifugal has a vertical impeller connected to a horizontal shaft, Figure 1. The vertical centrifugal has a horizontal impeller connected to a vertical shaft.

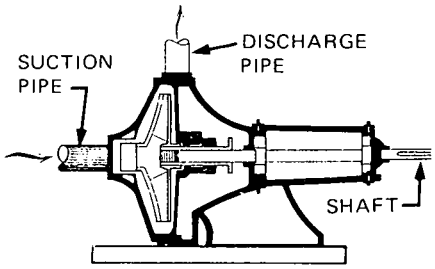


Figure 1. A horizontal centrifugal pump

Both types draw water into their impellers, so they must be set close to the water surface. In general, a centrifugal pump is limited to pumping from reservoirs, lakes, streams and shallow wells where the total suction lift is not more than 20 feet. However, they can be used as in-line booster pumps. Vertical centrifugals may be mounted so the impeller is under water at all times. This makes priming unnecessary, however, because the bearings are constantly under water, maintenance is usually high. Vertical centrifugals are usually limited to applications of 50 feet or less total pumping head.

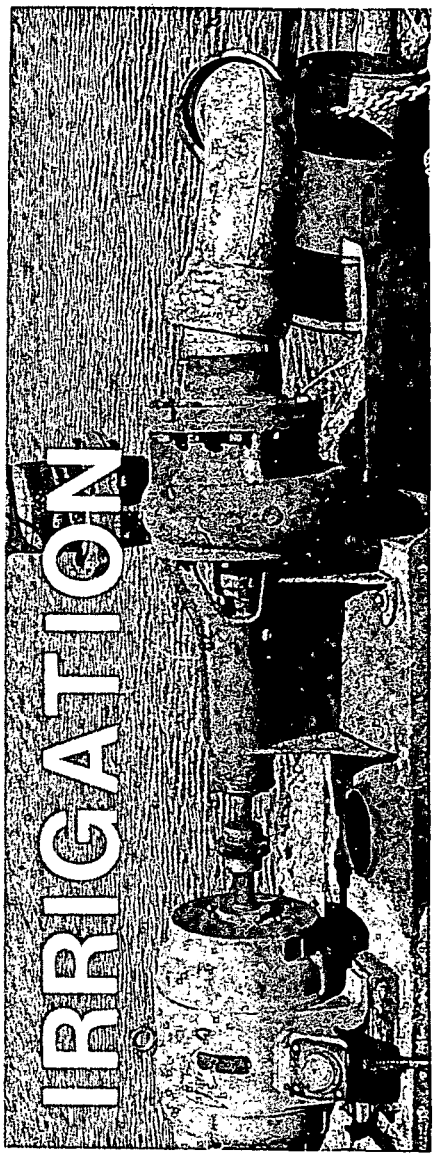
The horizontal centrifugals are most commonly used for irrigation. They are less costly, more maintenance free, easier to install and more accessible for inspection and maintenance than a vertical centrifugal.

Advantages and disadvantages for horizontal and vertical centrifugal pumps are shown in the tables on the following page.

OPERATING CHARACTERISTICS

Suction Lift

All centrifugal pumps must be completely filled with water before they can operate. After priming, the pump is started and the rotation of the impeller throws water towards the outside of the impeller by centrifugal force. This creates a vacuum, or an area of lower pressure, at the center of the impeller. Water from the suc-



tion pipe moves into the center of the impeller to replace that being thrown out. This water is at a higher pressure because of atmospheric pressure pushing down on the water surface.

A centrifugal pump operating above a water surface is operating with a suction lift. The allowable distance between the center of the impeller and the surface of the water is different for different pumps. Through tests manufacturers determine the "NPSH," net positive suction head, for their pumps. This NPSH is subtracted from 33 feet to determine the maximum suction head at which that pump will operate. For example, if a pump is found to require a minimum net positive suction head of 20 feet at a given temperature, speed, capacity and discharge head, the pump would have a maximum suction lift of 13 feet at sea level. The suction lift will be reduced by 1.2 feet for every 1,000 feet of elevation above sea level. This maximum suction lift must include not only the vertical suction lift, but also the friction losses in the intake pipe, friction losses through elbows, foot valves and other fittings. Because of these losses a pump rated for a maximum suction lift of 13 feet may only safely lift water 8 or 10 feet.

The operation of a pump at lifts greater than it was designed for, or under other conditions which result in excessive or rapidly fluctuating vacuum at some point in the impeller, may cause cavitation which could severely damage the pump. (Cavitation is the formation of air spaces in the moving water, caused either by air entering the suction line or excessively high suctions created in the pump.)

Total Head

The total dynamic head a pump will be operating at is a combination of several heads. By definition total dynamic head equals total static head plus pressure head plus friction head plus velocity head, Figure 2.

Total Static Head

Total static head is the total vertical distance the pump must lift the water. When pumping from a well, this would be the distance from the pumping water level in the well to ground level plus the distance the water is lifted from ground level to the discharge point.

Pressure Head

Sprinklers require pressure to operate. Center pivot systems require a certain pressure at the pivot point to distribute the water properly. Note: The pressure in PSI is normally converted to feet of head for calculation purposes (see Table 1). PSI x 2.31 = Head in Feet of Water.

Friction Head

Friction head is the loss due to friction when water flows through pipes. Additional friction loss also occurs when water flows through fittings or valves, around corners, or at increases or decreases in pipe size. Values for these losses are obtained from friction loss tables.

Table 1. PSI (Pounds Per Square Inch) Versus Head in Feet of Water

psi	Head (Ft)	psi	Head (Ft)	psi	Head (Ft)
0	0	35	80.8	70	162
5	11.5	40	92.4	75	173
10	23.1	45	104	80	185
15	34.6	50	115	85	196
20	46.2	55	127	90	208
25	57.7	60	138	95	219
30	69.3	65	150	100	231

HORIZONTAL CENTRIFUGAL PUMPS

Advantages

High efficiency is obtainable.

Efficiency remains high over a range of operating conditions.

Adaptable to a range of operating conditions.

Simple and economical.

Easy to install.

Does not overload with increased head.

Disadvantages

Suction lift is limited, should be within 20 feet of water surface.

Requires priming.

Loss of prime can damage pump.

May overload if head is decreased.

Available head per state is limited.

VERTICAL CENTRIFUGAL PUMPS

Advantages

May be exposed or submerged.

Submerged pump does not require priming.

Disadvantages

Maintenance costs may be high to the shaft and bearings.

Usually restricted to pumping heads of no more than 50 feet.

May overload if head is decreased.

More expensive than horizontal centrifugal.

Velocity Head

Velocity head is the energy given the water to get it into motion. This is a very small amount of energy and is usually negligible when computing losses in an irrigation system.

Pump Efficiencies

For any particular job, the best pump selection will be one that operates at peak efficiency. The power imparted to water as it moves through a pump may be calculated by the following formula:

$$WHP = \frac{Q \times TDH}{3960}$$

Q = Discharge in GPM (gallons per minute)

TDH = Total dynamic head in feet

However, the actual power required to run a pump will be higher than this because pumps are not 100 percent efficient. The brake horsepower required at the pump shaft will be this water horsepower divided by the pump efficiency as shown in the following formula:

$$BHP = \frac{WHP}{\text{Pump Efficiency}}$$

BHP = Brake Horsepower (continuous horsepower rating of power unit)

WHP = Water Horsepower

Manufacturers determine by tests the operating characteristics of their pumps. Choose a pump which delivers good efficiency at the discharge capacity and total dynamic head at which it will operate.

The pump curve in Figure 3 is typical. It represents the performance of one specific pump. The pump will operate over a wide range of conditions, but it will operate at peak efficiency under limited conditions.

First, take a look at the information on the curve.

1. Each curve will identify the type and model of pump represented.
2. The horizontal axis (across the bottom) will represent the discharge, usually in gallons per minute.
3. The vertical axis (up the left side) will represent the total dynamic head, usually in feet.
4. The RPM (revolutions per minute) curve shows how much water the pump will discharge at all heads and discharges covered in the curve at a given RPM.
5. The horsepower curve (dotted line) tells what horsepower must be delivered to the pump shaft to pump that amount of water at the required head.
6. The efficiency curves are alternately long and short dashed lines with the percentage figures at the ends. They indicate the efficiency at which the pump operates under that particular condition of discharge, speed and total dynamic head.

As an example for using a pump characteristic curve, determine the horsepower and efficiency of this pump at 480 GPM discharge and 180 feet of total head.

Solution: Follow the dashed line up from 480 GPM until it crosses the 180-foot dynamic head line. At this point the pump is running at a peak efficiency of 73 percent at a speed of 2,000 RPM and requires 30 horsepower on the input shaft.

Effect of Speed Change on Pump Performance

The performance of a pump varies with the speed at which it rotates. The capacity or rate of flow varies directly as the change in speed; that is, if the speed is increased by 50 percent, the capacity is increased by 50 percent. The head that the pump will develop, however, varies as the square of the ratio of the new speed to the old speed. Thus an increase of 50 percent in the speed means that the developed head will increase $(1.5/1)^2$ or 2.25 times. Further, the required horsepower increases as the cube of the ratio of change. This means that by increasing the speed by 50 percent the required horsepower will increase $(1.5/1)^3$ or 3.38 times that required at the lower speed.

Theoretically, varying the pump speed will result in changes in capacity, head and brake horsepower according to the following formulas:

$$\frac{rpm_2}{rpm_1} \times gpm_1 = gpm_2$$

$$\left(\frac{rpm_2}{rpm_1}\right)^2 \times H_1 = H_2 \text{ (in feet)}$$

$$\left(\frac{rpm_2}{rpm_1}\right)^3 \times bhp_1 = bhp_2$$

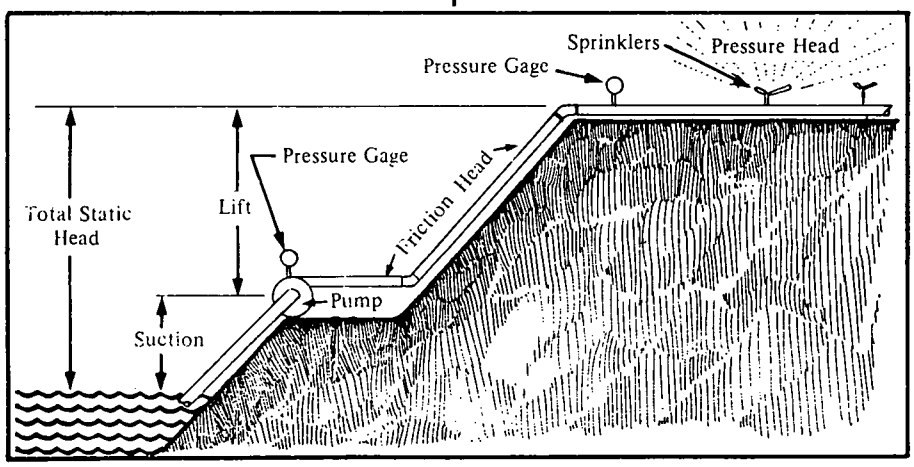


Figure 2. Total dynamic head is the sum of total static head plus friction head plus pressure head. Total dynamic head will equal gauge pressure reading at the pump x 2.31 plus the suction lift. Total dynamic head will also equal gauge pressure reading at the sprinklers x 2.31 plus total static head plus friction head.

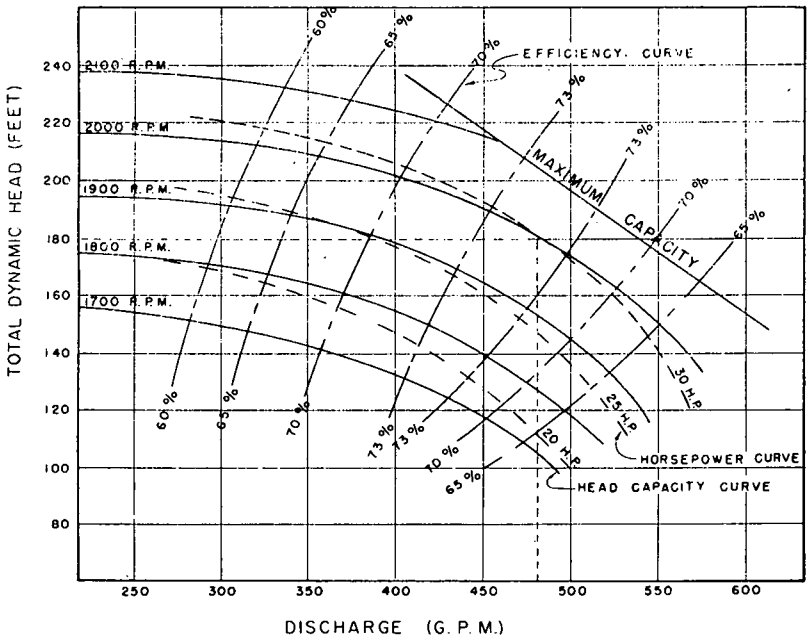


Figure 3. Typical characteristic curve for horizontal centrifugal pump

DEEP WELL TURBINE PUMPS

Deep well turbine pumps are adapted for use in cased wells or where the water surface is below the practical limits of a centrifugal pump. Turbine pump efficiencies are comparable with those of good horizontal centrifugal pumps. They will give long and dependable service if properly installed and maintained. However, they are usually more expensive than centrifugal pumps and are more difficult to inspect and repair.

Advantages

Adapted for use in wells.

Adapted for use where water surface fluctuates.

Can be adapted for high heads and large discharges.

Small chance of losing prime.

Disadvantages

Higher initial cost than centrifugal.

Requires closer setting than centrifugal pumps.

Efficient over narrower range of operating conditions than centrifugal pumps.

Requires additional stages for larger heads.

Difficult to install and repair.

The turbine pump has three main parts: (1) the head assembly, (2) the pump bowl assembly and the (3) shaft and column assembly. The head is normally cast iron, designed for installation on a foundation. It supports the column and shaft assembly and the bowl assembly in the well and provides a discharge for the water being delivered. It also accommodates the electric motor or right angle gear drive for connection to the power unit.

The pump bowl assembly contains the bowls and the impellers. Because of the limited diameter of the impellers, each impeller develops a relatively low head and it is necessary in average applications to stack several impellers in series one above the other with each in its own bowl or diffuser housing.

Each impeller unit raises the allowable head under which the pump will operate. This is called staging. Thus, a four-stage bowl assembly contains four impellers all attached to a common shaft through the separate housing or bowls and will operate at four times the discharge head of a single-stage pump.

The shaft and column assembly provides for the connection between the head and the pump bowl assembly. The line shaft carries the power and the column carries the water upward. The line shaft on a turbine pump may be either water lubricated or oil lubricated.

The oil-lubricated pump has an enclosed shaft into which oil drips, lubricating the bearings. The water lubricated pump has an open shaft. The bearings are lubricated by the pumped water. If any fine sand is being pumped, select the oil-lubricated pump because it will keep the sand out of the bearings. If the water is for domestic use, it must be free of oil and a water-lubricated pump would be used.

Line shaft bearings are commonly placed on 10-foot centers for

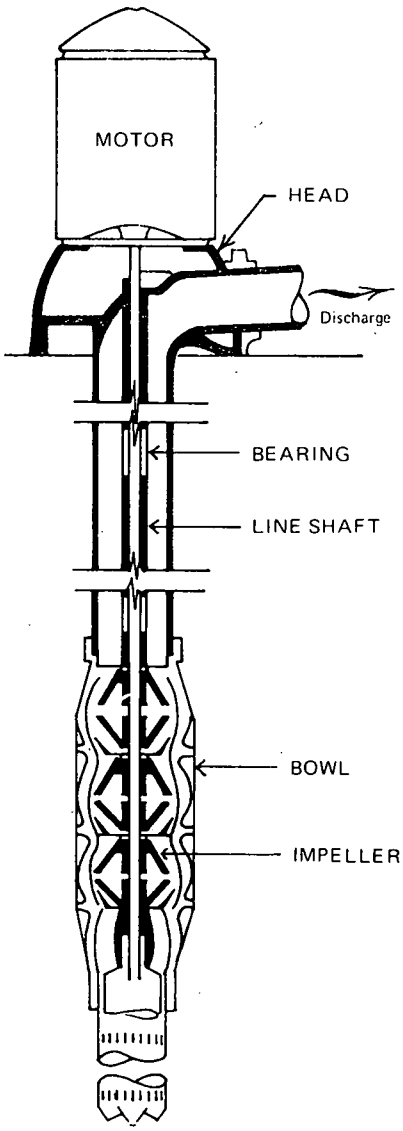


Figure 4. Deep-well turbine pump

water lubricated pumps operating at speeds under 2,200 RPM and at 5-foot centers for pumps operating at higher speeds. Oil-lubricated bearings are commonly placed on 5-foot centers.

OPERATING CHARACTERISTICS

Operating characteristics of deep well turbine pumps are determined by test and depend largely on the bowl design and by the speed of the impeller shaft. Head capacity, efficiency, horsepower and rate of speed are similar to those given for centrifugal pumps. Efficiency curves, in particular, are very similar if the pumps are operated at their designed speed. Turbines, however, cannot operate at a high efficiency over as wide a range of speed as can centrifugal pumps. This is because a high efficiency is possible only if the vanes in the bowl are in line with the flow of water as it leaves the tip of the impeller. When the speed of the impeller changes, the direction of flow of water leaving the impeller also changes. This causes turbulence against the vane and results in reduced efficiency.

The total head and power calculations which are used in the preceding section on centrifugal pumps will be the same for turbine pumps. The pump curves will be similar, contain the same information, and can be used in the same manner. However, pump curves for turbine pumps are normally shown as per stage so the total head obtained will be determined by multiplying the indicated head on the pump curve by the number of stages. Horsepower requirements must also be multiplied by the number of stages.

Impellers used in turbine pumps may be either semi-open or closed. A semi-open impeller has only the bottom side of the vanes closed. This bottom side runs with a close clearance to the pump bowl. This clearance is critical and must be adjusted when the pump is new. After an initial run-in and periodically afterwards check this clearance and make adjustments according to manufacturer's specifications. A misadjusted impeller clearance may cause an inefficient operating pump if the impellers are set too high. Mechanical damage will result if the impellers are set too low and the impellers are hitting the bowls. The adjustment of a pump having closed impellers is not as critical, however, they must still be checked and adjusted to manufacturer's specifications. Semi-open impeller adjustments are normally made starting from the bottom of the bowl while closed impeller adjustments are normally made starting from the top. Make impeller adjustments by tightening or loosening the adjustment nut located at the top of the head assembly.

INSTALLATION OF TURBINE PUMPS

Deep well turbine pumps must have correct alignment between the pump and the power unit. Align the pump in the well casing so that no part of the pump assembly touches the well casing. This is important because vibration in the pump assembly will wear holes in the well casing whenever the two come into contact.

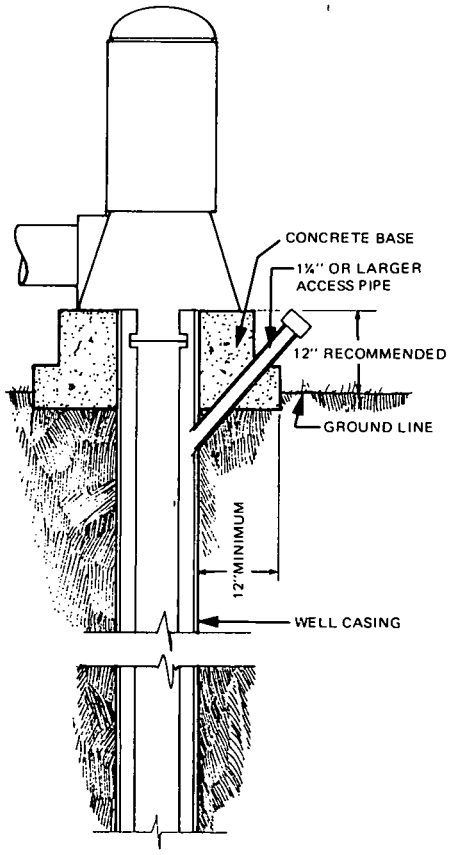


Figure 5. Recommended concrete base with access pipe for naturally developed wells.

The pump must be mounted on a good foundation so that its alignment between pump and drive and pump and well casing will be maintained at all times. A foundation of concrete provides the most permanent and trouble-free installation. The foundation must be large enough so that the pump and drive assembly can be securely fastened. The foundation should have at least 12 inches of bearing surface on all sides of the well. In the case of a gravel-packed well, measure this 12-inch clearance from the outside edge of the gravel packing. When the pump is installed in a gravel-packed well, provide at least two openings in the foundation on opposite sides of the well to permit refilling with gravel as the gravel-pack settles.

Figure 5 shows recommended concrete base and access pipe construction for irrigation wells.

SUBMERSIBLE PUMPS

A submersible pump is simply a turbine pump close-coupled to a submersible electric motor attached to the lower side of the turbine, Figure 6. Both pump and motor are suspended in the water, thereby eliminating the long-line shaft and bearing retainers that are required normally for a conventional deep well turbine pump. Operating characteristics are the same as described for deep well turbine pumps.

The pump, a centrifugal-type turbine, is equipped with either closed or open impellers or some modification of these two types arranged in series. The closed impeller type generally is used where it is necessary for the pump to develop high pressures. Water enters the pump through a screen located between the motor and pump.

The submersible motors are smaller in diameter and much longer than ordinary motors so they may be inserted in wells of the usual diameters. These motors are made in various ways, but generally are referred to as dry motors and wet motors. Dry

motors are hermetically sealed to exclude water from the motor. The motor is filled with a high dielectric oil. Wet motors are open to the well water with the rotor and bearings actually operating in the water.

Submersible pumps are available in a wide range of capacities for four-inch and larger wells. However, in larger sizes it may cost relatively more because the motors are quite expensive.

Advantages

Can be used in deep wells.

No priming necessary.

May be used in crooked wells.

Ease of installation.

Disadvantages

Higher price in larger sizes than deep well turbines.

Adjustment impossible without removing from well.

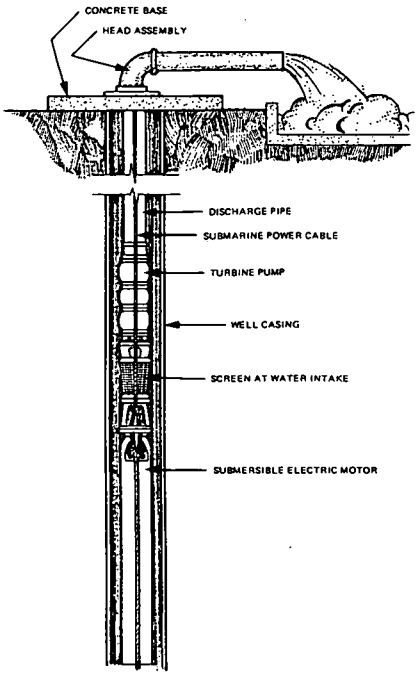


Figure 6. A submersible pump

PROPELLER PUMPS

Propeller pumps, Figure 7, are chiefly used for low lift, high gallonage conditions. They come in two types, axial (screw) and mixed-flow. The difference between the two is the type of impeller. The axial flow pump is essentially a low head pump. A single-stage pump will operate against 10 feet of head. By adding additional stages, heads of from 30 to 40 feet are obtainable. The mixed-flow pump is designed for large capacities, up to 50,000 gallons per minute, at moderate heads.

Power requirements of the propeller pump increase directly as the head so adequate power must be provided to drive the pump at maximum lift. Propeller pumps are not suitable under conditions where it is necessary to throttle the discharge to secure reduced delivery. It is important to accurately determine the maximum total head against which this type of pump will operate.

Propeller pumps are not suitable for suction lift. The impeller bowl must be submerged with the pump operating at the proper submergence depth. Different makes and sizes of pumps require different submergence depths. So always follow the recommendations of the pump manufacturer. Failure to observe required submergence depth may cause severe mechanical vibrations and rapid deterioration of propeller blades

Advantages

Simple construction.

Adaptable to high flow against low heads.

(0-25 feet for axial-flow pump)
(6-45 feet for mixed-flow pump)

Efficient at variable speeds.

Can pump some sand with water.

Needs no priming.

Disadvantages

Not suitable for suction lift.

Requires proper clearance between walls and bottom of pump.

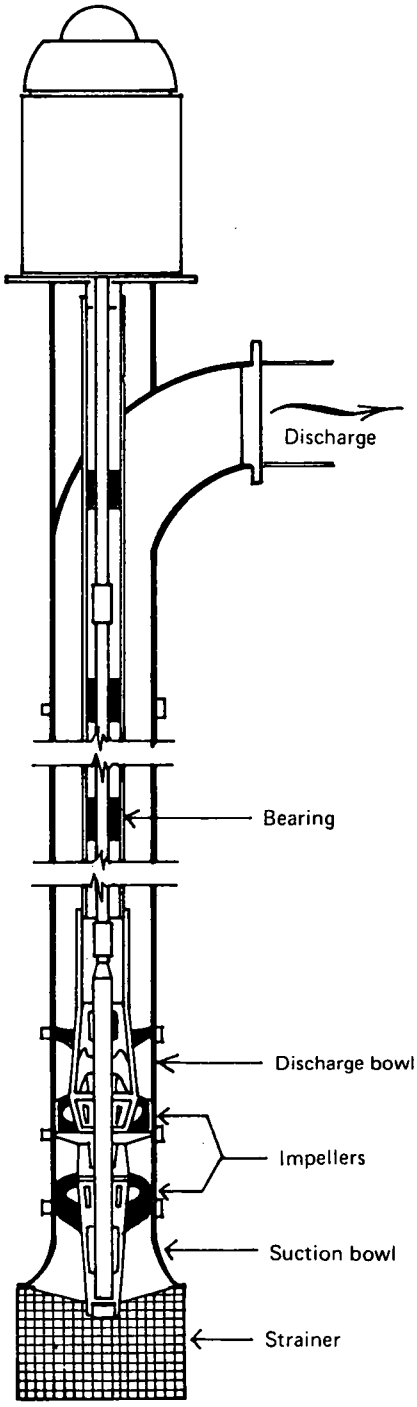


Figure 7. Propeller pump

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