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SPRINKLER IRRIGATION GUIDEBOOK

By

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U.S. Agency for International Development
Office of War On Hunger
Agriculture and Rural Development Service
Washington, D.C. - 20523

January 1969

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FOREWORD

Sprinkler irrigation is relatively new and much remains to be learned of its many facet relationships to irrigated agriculture. New developments in the fields of mechanization, materials, instrumentation and application techniques are constantly being introduced and tested by numerous private and public agencies. It has created an industry which is rapidly growing world wide.

This publication is only a brief exposé of the subject and it is hoped that it will encourage the design engineer and others concerned to obtain additional technical publications and thereby develop a more complete understanding of the subject.

The author wishes to acknowledge his major source material listed in the bibliography. He also expresses his appreciation to Dr. Omer Kelley of the U.S. Agency for International Development and to Mr. Tyler Quackenbush, Chief Irrigation Engineer, Soil Conservation Service, U.S. Department of Agriculture, for technical review of the manuscript; to the Water Resource Engineers of A.I.D., Washington, who materially assisted in the development of the basic outline for the publication and in subsequent review of the material; also to Dr. William Raney, Agricultural Research Service, U.S.D.A. and Dr. Roy Dawson, Food and Agriculture Organization, United Nations for their constructive suggestions. The author has made liberal use of handbook type tables and data from various manufacturers literature and other industrial sources for which he is grateful.

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Sprinkler Irrigation Engineer

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BACKGROUND AND PURPOSE

The earliest sprinkler irrigation installations in the United States were made in about 1900; however, it has only been in the last 25 years that it has become significant in terms of total irrigated area. In fact, the largest increase has come since 1946 with the advent of light weight portable pipe with "quick" couplers as well as improved accessory equipment and many innovations in design and application methods. Worldwide need for increased food supplies and the steadily growing value of land are also strong incentives for this growth.

The purposes of this publication are fourfold:

1. To assist technicians of overseas A. I. D. Missions and their host country counterparts in checking the engineering of proposed planned systems as to adequacy and efficiency.

2. To provide guidelines for analyzing a potential sprinkler installation prior to proceeding with the design.

3. To present a step by step procedure, with examples, for designing a basic sprinkler system.

4. To have under "one cover" the various agricultural and engineering tables and charts in English and metric units and conversion factors to enable engineers to make their engineering calculations directly in either terminology.

It is very important for agricultural technicians and others concerned with irrigation development to become familiar with sprinkler irrigation: First, to determine if the sprinkler method is applicable or desirable for specific installations; and, second, to be able to either check the design of others or to do the basic design work. For some reason, sprinkler systems have "glamour" and there is the hazard of "jumping" to a decision to proceed without making prior engineering and economic analysis. Also, costly mistakes can easily be made unless all factors (agricultural and engineering) are considered at the outset.

This publication is <u>not</u> for the purpose of "selling" sprinkler irrigation. Neither does it contain all of the data and background information for an inexperienced layman to become an irrigation specialist. It presupposes the reader has an engineering background in hydrology and pumps, and that he is either familiar with irrigated agriculture or is working with agricultural technicians who will provide the necessary background agricultural information.

It should also be noted at the outset that the data presented must necessarily be taken in context with the specific climatic and hydrological conditions prevalent in the

area in which it is to be applied. Local conditions and other background data in irrigated agriculture are extremely important and should be studied by the planner so that adjustments can be made to take them into account. Basically, however, any irrigation system must be similarly adapted to fit the soils, topography, crops, climate, water supply and farming operations. Also, it must meet the peak-use requirements and planned to operate at maximum practical efficiency.

A selected list of reference publications is included in the Appendix for those desiring to make further studies of the subject.

SPRINKLER DEVELOPMENT - WORLD-WIDE

As previously mentioned large scale development of sprinkler irrigation did not get under way until about 1946, however, since that year there has been a tremenduous growth particularly in Continental Europe and in the United States. Complete records are not available but it appears that in 1967, from 2.4 to 2.6 million hectares were sprinkler irrigated in Europe (not including Russia for which data were not available). At the end of 1967 there were about 3.0 million hectares sprinkler irrigated in the United States representing about 17% of the total irrigated area. (1 hectare = 2.47 acres).

Sprinkler irrigation in other countries is under varying degrees of development. In Israel 144,000 hectares representing over 95% of the total irrigated area is by sprinklers. A number of installations have been made with more planned, in Tunisia, Libya and Turkey. Experimental units were installed in Taiwan in 1952 for irrigating sugar cane with encouraging results. The Tokyo University in Japan has conducted extensive research on sprinkler irrigation. Many other countries world wide are testing this method of irrigation. It is not unreasonable to estimate the present world wide development at about 6 million hectares which is significant not only from the standpoint of the gain in world food production but also that it was accomplished almost entirely by individual farmers with their own financial resources.

TYPES OF SPRINKLER SYSTEMS

Sprinkler systems are classified in the following major types:

1. Nozzle - Line Systems

Small bore nozzles are placed in standard water pipe at uniform intervals along its length and the pipe rotated through about 90° (by hand or by hydraulic pump) to irrigate a rectangular strip. The pipe is mounted on posts above the crop height with the assembly usually permanent. The spacing between lines is about 15 meters (50 feet) with operating pressures of 1.7 to 2.8 kg./sq. cm. (25 to 40 psi*).

This system was the "pioneer" in sprinkler irrigation and has been in use in the United States since 1900; however, its application is generally limited to small areas and primarily for nurseries and truck crops.

---

*psi is abbreviation for pounds per square inch.
kg/sq. cm. is kilograms per square centimeter.

2. Perforated Portable Pipe Systems

This method consists of drilled holes in portable thinwall tubing to irrigate a 12 meter (40') width strip in a fairly uniform distribution pattern. The system is usually designed for relatively low operating pressures (about 1 kg./sq. cm. or 15 psi) however, even though the perforations are as small as practicable, the application rates range from 1.25 to 5 cm. (.5 to 2.") per hour for various pressures and spacings. It is therefore limited to use on soils having fairly high intake rates.

3. Revolving Sprinkler System

The use of slow revolving sprinklers has become very popular and is adapted for small or large systems. It consists basically of sprinklers either installed on a pipe line, on portable quick coupling lateral pipe, or with some type of moving device.

Due to its versatility and wide spread acceptance, it is the method to be treated in this publication. The basic crop and application principles, however, are the same for all three methods noted above.

Within the revolving sprinkler method comes three general subclassifications:

a. Hand move systems where the lateral line is manually moved across the irrigated area.

b. Mechanical move systems employing a variety of devices for moving the lateral line by rotating "booms", tow, drag, wench, or wheel lines, or sprinklers on a rotating tower arrangement.

c. Solid set systems where the entire irrigated area is equipped by a set of sprinklers operated either simultaneously or in sequence by automatic timed or manual controls.

All of these revolving sprinkler methods have their advantages and limitations. It is believed, however, that in developing countries where farm labor costs are low and investment capital limited the "hand move" system will predominate for many years and for this reason the design and examples given are for hand move systems. The design engineer however, is urged to secure literature and become familiar with both the mechanical and solid set systems. There may be installations, particularly in large operations where the mechanical systems are advantageous. The solid set system has application in nurseries, intensive high value crops, for temperature control of certain crops, and where it is difficult to move the sprinkler line.

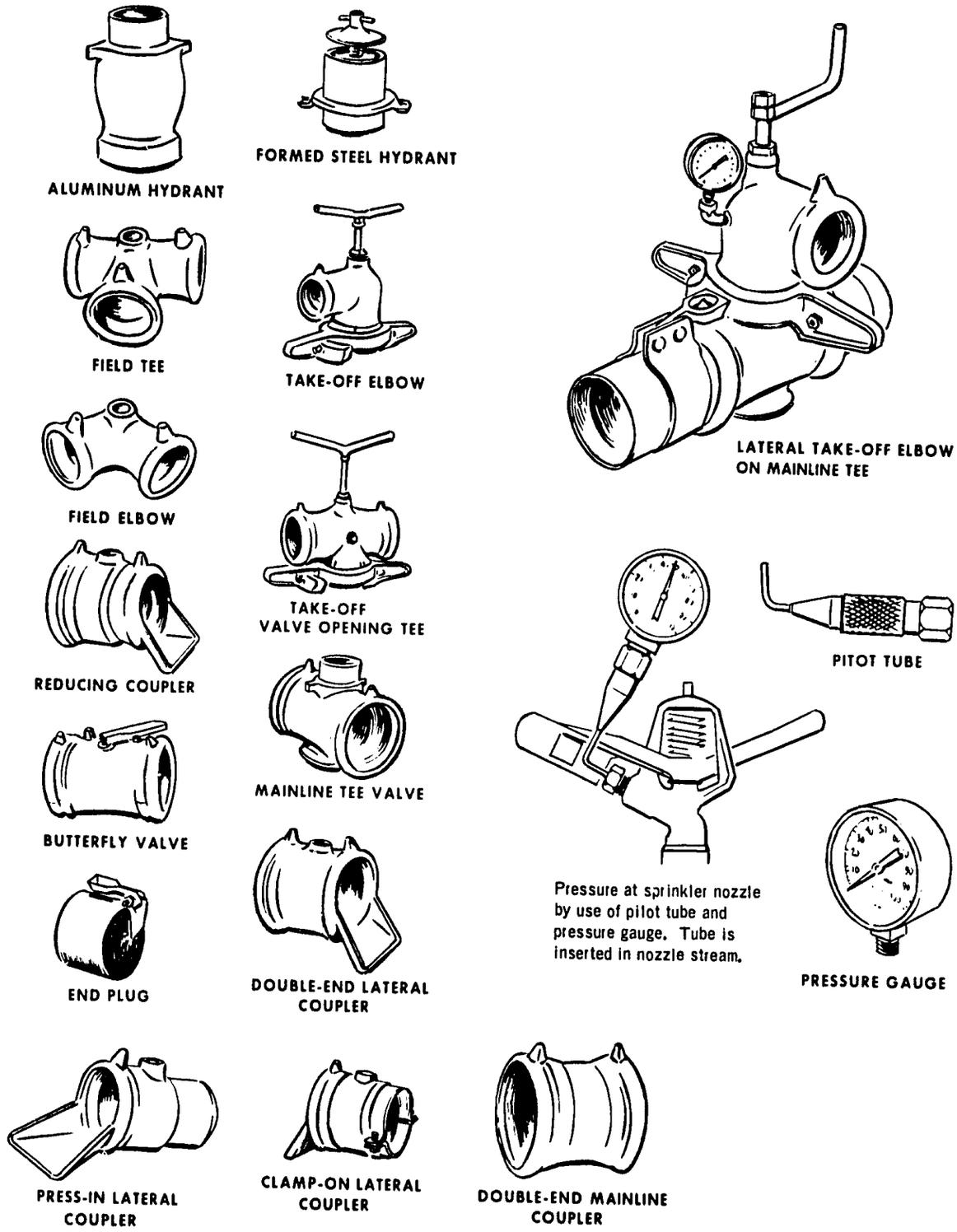


Figure 9. Typical Irrigation Fittings.

PLACE OF SPRINKLER METHOD

The customary reasons given for selecting the sprinkler method are:

1. Land unsuitable or uneconomical for leveling.

2. Limited rate of flow of water from a water source to prove for efficient flooding or furrow irrigation.

3. Porous, highly erodible or relatively impermeable soil which would be difficult to irrigate by other methods.

4. Where frequent light applications are desired.

These are certainly valid reasons for considering the sprinkler method. Yet there are many thousands of hectares of land sprinkler irrigated where conventional gravity systems would be equally applicable. Even in areas where land had been leveled, many farmers are purchasing sprinkler systems. Other reasons given are:

1. Elimination in some cases of on-the-farm ditches and canals, their annual maintenance and water loss.

2. Close control of water application even by inexperienced operators. This may also result in saving of water and possible higher crop yields.

3. Fertilizer application and application of pesticides.

4. In some cases for other management reasons such as frost protection and high temperature control.

All of these factors should be considered by the farmer or planner. The economics of any system of course must be taken into account and above all an open mind is necessary. There appears to be a tendency for engineers and others to divide into "camps", one disclaiming sprinklers per se and the other to consider no other alternatives.

Above all, irrigation planning should always be a "team approach" with the farmer, engineer, soils and crop management specialists and economist making their individual contributions. Unless this approach is taken, serious mistakes can be made that may profoundly affect the end result. There are, unfortunately, too many "monuments" world wide where some irrigation projects of all types were inadequately planned at the outset by farmers or others resulting in economic losses and much time and money spent in an attempt to correct the defects. Sprinkler irrigation, therefore, should be very carefully studied and a systematic procedure followed in all the ramifications of initial planning.

This publication although primarily considering the engineering phases of sprinkler irrigation design does include certain agricultural design data of value for any type of system. These data must necessarily be general in character and it is again emphasized that the engineer must team up with his counterparts throughout the entire planning process. When this is done, the sprinkling method will find its logical place in the development of irrigated agriculture.

PLANNING THE SYSTEM

From a planning standpoint, there are two common categories of sprinkler systems:

1. Farm system - wherein the entire system is planned for an individual farm or a part of a farm. It can be small or large but in general consists of one individual farm owner or operator and with a fairly well defined crop plan.

2. Cooperative or community system. Usually these are large systems with many individual farm units. The cropping patterm in some projects may be clearcut; i.e., a rotation crop system with specified crops, or it may be the delivery of water to specified locations on a continuous flow or rotation basis with the individual farmer determining the application on his own farm.

The planning of this community or cooperative system is a more complex agricultural and engineering problem and also involves more detailed economic analysis for securing financing and preparation of specifications and bid documents for equipment and construction. In most cases, particularly in developing countries, the design work will be done either by a government agency or by a qualified consultant or engineering consulting firm, particularly where large areas are involved.

The same general design procedures are followed, however, except for size and detail. The procedures which follow are "geared" to the individual farm system; however, they are equally applicable to a multi-farm operation and can be used as guidelines in either checking the designs of others or in the planning procedure itself.

Acknowledgement for the planning procedure used herein is made to the Soil Conservation Service of the U.S. Department of Agriculture. This agency adopted this "system" in 1948 and it has stood the test of many thousands of systems installed via its guidance.

This plan has 18 specific steps outlined on page 15.

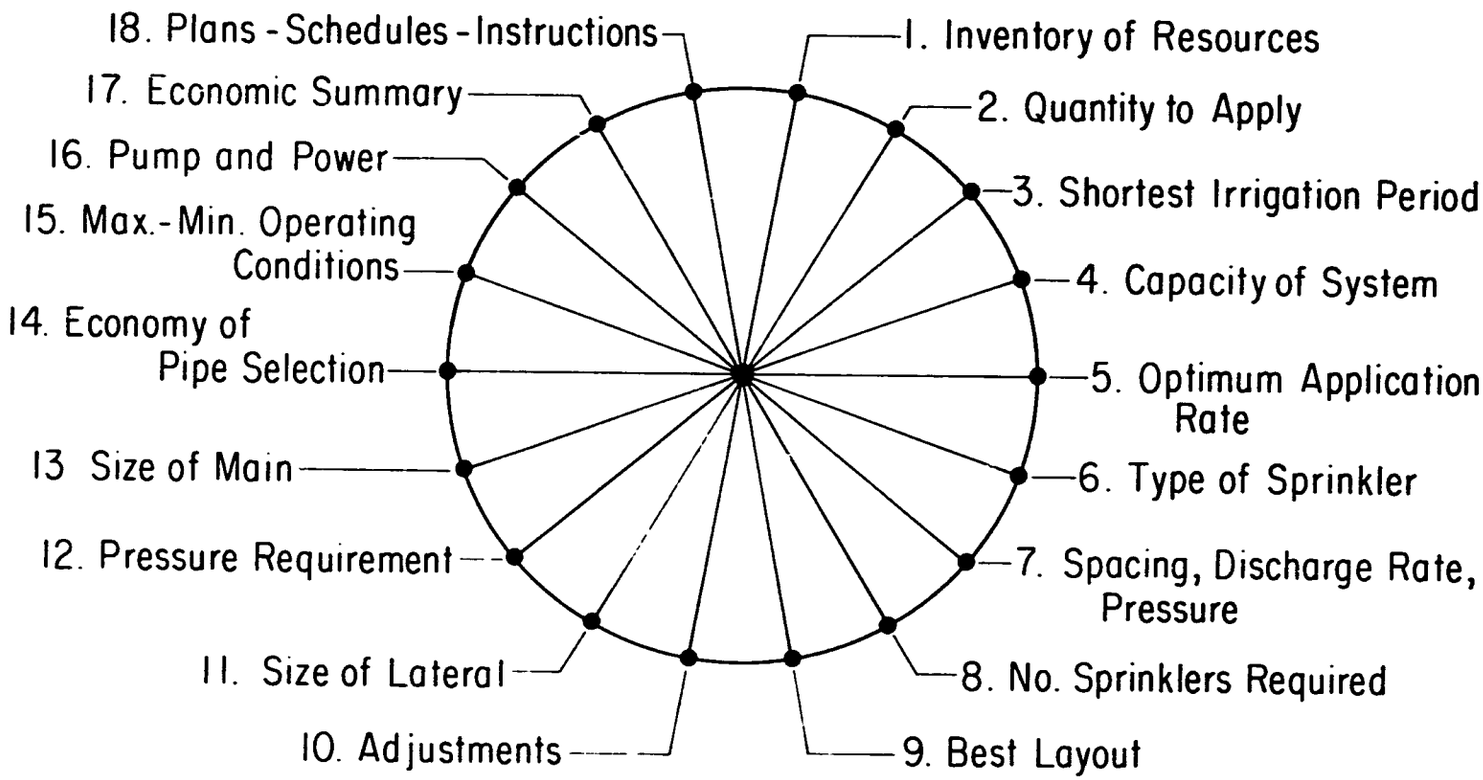


Figure 10. The 18 steps in design of a sprinkler system.

BASIC DATA PRIOR TO DESIGN OF A SPRINKLER SYSTEM

Assuming that a tract of suitable land has been tentatively selected for sprinkler irrigation, a certain routine is recommended for the planners in order to obtain the basic data prior to proceeding with the actual design of the system.

1. Water Quality

This is the key factor that should precede any detailed study. Obviously, if water is of unsatisfactory chemical quality the project should be abandoned. Chemical analysis of the water should be made from which the agronomist can determine its suitability for specified crops and soils, also as to its possible corrosive effect on the pipe and equipment.

2. Water Supply

The next consideration is whether there is sufficient water to meet the crop requirements for the planned area, both for peak requirements and in determining annual consumption. (See page 17 for method of obtaining these data)

The peak and annual water use of any crop is a function of many factors including climate, growing season, soil, topography, wind movement and irrigation practices. In areas or regions where irrigation has been practiced and records obtained the design engineer can use these data; however, where data or prior experience is not available it becomes a task of studying and adapting data from other regions of comparable climatic and soil conditions. Nearly every country has accumulated data and made comparative studies with other regions. Great care, however, is necessary in making these comparisons. Serious errors could result if all the variables were not properly considered. Research on water use and management is encouraged in each country to obtain these highly important data. Many countries require that approval and a water right be obtained prior to its use for irrigation.

Maps and Other Data

1. A scaled dimensional map of the area to be irrigated should be prepared showing roads, buildings and other obstructions, portions not to be irrigated, and water source and possible pump locations.

2. Elevations and contour lines should be shown on the map. Where slopes are fairly uniform, elevations can be at 5 to 10 meter (15 to 30 foot) intervals; however, where there are marked changes, 1 to 3 meter (3 to 10 foot) intervals are recommended.

3. Soil types should be noted, with water requirements if variations are significant.

4. Where several crops are to be grown, boundaries of each should be noted, and for tree crops the tree spacing.

5. Power available for pump, or pressure head in case of a gravity supplied water supply.

Available Sprinkler Equipment

An engineer cannot design a system for a specific installation without a complete knowledge of available equipment. In recent years most every country has either a source of locally fabricated sprinkler equipment or an import arrangement with country based representatives. It is strongly recommended that the designer become familiar with the equipment that is locally available as well as the availability of repair parts and service arrangements. Where sprinkler development is relatively new in a country, these factors are of extreme importance and should precede any design work.

Estimating Consumptive-Use

Many countries are using the Blaney-Criddle formula to estimate monthly and seasonal crop water requirements. This method requires having local climatological data and the use of emperical crop growth (k) coefficients. It is based on the assumption that consumptive-use (evapo-transpiration) varies with the temperature, daytime hours and available moisture. By multiplying the mean monthly temperature (t) by the monthly percent of daytime hours of the year (p) there is obtained a monthly consumptive-use factor (f). It is assumed that the consumptive-use varies directly as this factor when an ample water supply is available.

Expressed mathematically:

$U = KF$ = sum of kf where:

U = Consumptive-use of crop (or evapo-transpiration) for any period.

F = Sum of the monthly consumptive-use factors for the period. (sum of the products of mean monthly temperature and monthly percent of daytime hours of the year)

k = empirical-consumptive use crop coefficient for a month (varies by crops)

t = mean monthly temp. in F^o

p = monthly percentage of daylight hours in the year for the latitude

$f = \frac{t \times p}{100}$

$u = kf$ = monthly consumptive-use in inches

In metric units:

$U = kp\,(.457t + 8.13)$ = monthly consumptive-use in millimeters

t = mean monthly temp. in C^o

Blaney and Criddle* have prepared a reference table (Table 1) for the seasonal K coefficient for various crops which, although admittedly variable due to lack of world wide reference data and other factors, can be used for design purposes. Locally developed K coefficients, of course, should be used wherever available.

*Technical Bulletin No. 1275, Agricultural Research Service, United States Department of Agriculture in cooperation with Office of Utah State Engineer.

Table 1. Seasonal consumptive-use crop coefficients (K) for irrigated crops

Crop	Length of Normal Growing Season or Period 1/	Consumptive-use coefficient (K) 2/
Alfalfa	Between frosts	0.80 to 0.90
Bananas	Full year	.80 to 1.00
Beans	3 months	.60 to .70
Cocoa	Full year	.70 to .80
Coffee	Full year	.70 to .80
Corn (Maize)	4 months	.75 to .85
Cotton	7 months	.60 to .70
Dates	Full year	.65 to .80
Flax	7 to 8 months	.70 to .80
Grains, small	3 months	.75 to .85
Grain, sorghums	4 to 5 months	.70 to .80
Oilseeds	3 to 5 months	.65 to .75
Orchard crops:		
Avocado	Full year	.50 to .55
Grapefruit	Full year	.55 to .65
Orange and lemon	Full year	.45 to .55
Walnuts	Between frosts	.60 to .70
Deciduous	Between frosts	.60 to .70
Pasture crops:		
Grass	Between frosts	.75 to .85
Ladino whiteclover	Between frosts	.80 to .85
Potatoes	3 to 5 months	.65 to .75
Rice	3 to 5 months	1.00 to 1.10
Soybeans	140 days	.65 to .70
Sugar beet	6 months	.65 to .75
Sugarcane	Full year	.80 to .90
Tobacco	4 months	.70 to .80
Tomatoes	4 months	.65 to .70
Truck crops, small	2 to 4 months	.60 to .70
Vineyard	5 to 7 months	.50 to .60

1/ Length of season depends largely on variety and time of year when the crop is grown. Annual crops grown during the winter period may take much longer than if grown in the summertime.

2/ The lower values of (K) for use in the Blaney-Criddle formula, U = KF, are for the more humid areas, and the higher values are for the more arid climates.

Table 2. Monthly percentage of daytime hours of the year

FOR LATITUDES 0° TO 65° NORTH OF THE EQUATOR

Latitude North	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
65°	3.45	5.14	7.90	9.02	12.65	14.12	13.66	11.25	8.55	6.60	4.12	2.64
64°	3.75	5.30	7.93	9.87	12.42	13.60	13.31	11.15	8.58	6.70	4.35	3.04
63°	4.01	5.40	7.95	9.83	12.22	13.22	13.02	11.04	8.60	6.79	4.55	3.37
62°	4.25	5.52	7.99	9.75	12.03	12.91	12.79	10.92	8.50	6.86	4.72	3.67
61°	4.46	5.61	8.01	9.71	11.88	12.63	12.55	10.84	8.55	6.94	4.89	3.93
60°	4.67	5.70	8.05	9.66	11.72	12.39	12.33	10.72	8.57	7.00	5.04	4.15
59°	4.81	5.78	8.05	9.60	11.61	12.23	12.21	10.60	8.56	7.07	5.09	4.31
58°	4.99	5.85	8.06	9.55	11.44	12.00	12.00	10.56	8.56	7.13	5.13	4.55
57°	5.14	5.93	8.07	9.51	11.32	11.77	11.87	10.47	8.54	7.19	5.27	4.69
56°	5.29	6.00	8.10	9.45	11.20	11.67	11.69	10.40	8.52	7.25	5.54	4.89
55°	5.39	6.06	8.12	9.41	11.11	11.53	11.59	10.32	8.51	7.30	5.62	5.01
54°	5.53	6.12	8.15	9.36	11.00	11.40	11.43	10.27	8.50	7.33	5.74	5.17
53°	5.64	6.19	8.16	9.32	10.88	11.31	11.34	10.19	8.52	7.38	5.83	5.31
52°	5.75	6.23	8.17	9.28	10.81	11.13	11.22	10.15	8.49	7.40	5.94	5.43
51°	5.87	6.25	8.21	9.26	10.76	11.07	11.13	10.05	8.48	7.41	5.97	5.46
50°	5.98	6.32	8.25	9.25	10.69	10.93	10.99	10.00	8.44	7.43	6.07	5.65
48°	6.13	6.42	8.22	9.15	10.50	10.72	10.83	9.92	8.45	7.56	6.24	5.86
46°	6.30	6.50	8.24	9.09	10.37	10.54	10.66	9.82	8.44	7.61	6.38	6.05
44°	6.45	6.59	8.25	9.04	10.22	10.38	10.50	9.73	8.43	7.67	6.51	6.23
42°	6.60	6.66	8.28	8.97	10.10	10.21	10.37	9.64	8.42	7.73	6.63	6.39
40°	6.73	6.73	8.30	8.92	9.99	10.08	10.34	9.56	8.41	7.78	6.73	6.53
38°	6.87	6.79	8.34	8.90	9.92	9.95	10.10	9.47	8.38	7.80	6.82	6.66
36°	6.99	6.86	8.35	8.85	9.31	9.83	9.99	9.40	8.36	7.85	6.92	6.79
34°	7.10	6.91	8.36	8.80	9.72	9.70	9.88	9.33	8.36	7.90	7.02	6.92
32°	7.20	6.97	8.37	8.72	9.63	9.60	9.77	9.28	8.34	7.93	7.11	7.05
30°	7.30	7.03	8.38	8.72	9.53	9.49	9.67	9.22	8.34	7.99	7.19	7.14
28°	7.40	7.02	8.39	8.68	9.46	9.38	9.58	9.16	8.32	8.02	7.27	7.27
26°	7.49	7.12	8.40	8.64	9.37	9.30	9.49	9.10	8.32	8.06	7.36	7.35
24°	7.58	7.17	8.40	8.60	9.30	9.19	9.41	9.05	8.31	8.10	7.43	7.46
22°	7.76	7.22	8.41	8.57	9.22	9.12	9.31	9.00	8.30	8.13	7.50	7.56
20°	7.73	7.26	8.20	8.52	9.14	9.02	9.25	8.95	8.30	8.19	7.58	7.88
18°	7.88	7.26	8.40	8.46	9.06	8.99	9.20	8.81	8.29	8.24	7.67	7.89
16°	7.94	7.30	8.42	8.45	8.98	8.98	9.07	8.80	8.28	8.24	7.72	7.90
14°	7.08	7.39	8.43	8.44	8.90	8.73	8.99	8.79	8.28	8.28	7.85	8.04
12°	8.08	7.40	8.44	8.43	8.84	8.64	8.90	8.78	8.27	8.28	7.85	8.05
10°	8.11	7.40	8.44	8.43	8.81	8.57	8.84	8.74	8.26	8.29	7.89	8.08
8°	8.13	7.41	8.45	3.39	8.75	8.51	8.77	8.70	8.25	8.31	7.89	8.11
6°	8.19	7.49	8.45	8.39	8.73	8.48	8.75	8.69	8.25	8.41	7.95	8.19
4°	8.20	7.58	8.46	8.33	8.65	8.40	8.67	8.63	8.21	8.43	7.95	8.20
2°	8.43	7.62	8.47	8.22	8.51	8.25	8.52	8.50	8.20	8.45	8.16	8.42
0°	8.49	7.67	8.49	8.22	8.49	8.22	8.49	8.49	8.19	8.49	8.22	8.49

FOR LATITUDES 0° TO 50° SOUTH OF THE EQUATOR

Latitude South	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0°	8.49	7.67	8.49	8.22	8.49	8.22	8.49	8.49	8.19	8.49	8.22	8.49
2°	8.55	7.71	8.49	8.19	8.44	8.17	8.43	8.44	8.19	8.52	8.27	8.55
4°	8.64	7.76	8.50	8.17	8.39	8.08	8.20	8.41	8.19	8.56	8.33	8.65
6	8.71	7.81	8.50	8.12	8.30	8.00	8.19	8.37	8.18	8.59	8.38	8.74
8°	8.79	7.84	8.51	8.11	8.24	7.91	8.13	8.32	8.18	8.62	8.47	8.84
10°	8.85	7.86	8.52	8.09	8.18	7.84	8.11	8.28	8.18	8.65	8.52	8.90
12°	8.91	7.91	8.53	8.06	8.15	7.79	8.08	8.26	8.17	8.67	8.58	8.95
14°	8.97	7.97	8.54	8.03	8.07	7.70	7.08	8.19	8.16	8.69	8.65	9.01
16°	9.09	8.02	8.56	7.98	7.96	7.57	7.94	8.14	8.14	8.76	8.72	9.17
18°	9.18	8.06	8.57	7.93	7.99	7.50	7.88	8.90	8.14	8.80	8.80	9.24
20°	9.25	8.09	8.58	7.92	7.83	7.41	7.73	8.05	8.13	8.83	8.85	9.32
22°	9.36	8.12	8.58	7.89	7.74	7.30	7.76	8.03	8.13	8.86	8.90	9.38
24°	9.44	8.17	8.59	[illegible]	7.60	7.24	7.58	7.99	8.12	8.89	8.96	9.47
26°	9.52	8.28	8.00	[illegible]	7.56	7.07	7.49	7.87	8.11	8.94	9.10	9.61
28°	9.61	8.31	8.61	[illegible]	7.49	6.99	7.40	7.85	8.10	8.97	9.19	9.74
30°	9.69	8.33	8.63	7.75	7.43	6.94	7.30	7.80	8.09	9.00	9.24	9.80
32°	9.76	8.36	8.64	7.70	7.39	6.85	7.20	7.73	8.08	9.04	9.31	9.87
34°	9.88	8.41	8.65	7.68	7.30	6.73	7.10	7.69	8.06	9.07	9.38	9.99
36°	10.06	8.53	8.67	7.61	7.10	6.59	6.99	7.59	8.06	9.15	9.51	10.21
38°	10.14	8.61	8.68	7.59	7.03	6.46	6.87	7.51	8.05	9.19	9.60	10.34
40°	10.24	8.65	8.70	7.54	6.96	6.33	6.73	7.46	8.04	9.23	9.69	10.42
42°	10.39	8.72	8.71	7.49	6.85	6.20	6.60	7.39	8.01	9.27	9.79	10.57
44°	10.52	8.81	8.72	7.44	6.73	6.04	6.45	7.30	8.00	9.34	9.91	10.72
46°	10.68	8.88	8.73	7.39	6.61	5.87	6.30	7.21	7.98	9.41	10.03	10.90
48°	10.85	8.98	8.76	7.32	6.45	5.69	6.13	7.12	7.96	9.47	10.17	11.09
50°	11.03	9.06	8.77	7.25	6.31	5.48	5.98	7.03	7.95	9.53	10.32	11.30

The seasonal consumptive-use coefficient (K) is not a constant for consecutive short-time periods but varies considerably throughout the growing season of a crop. It is necessary therefore to make two modifications in the Blaney-Criddle formula to obtain reasonable accurate estimates of monthly consumptive-use. This involves the determination of a crop growth stage coefficient (k_c) and a climatic coefficient (k_t) for the period. The monthly consumptive-use coefficient (k) is the product of $k_c \times k_t$.

The U.S. Department of Agriculture, Soil Conservation Service has prepared a table for the value of (k_t) at various mean temperatures, and from research data has developed crop growth stage curves for 19 crops from which the value of (k_c) can be obtained for any period of growth.

To illustrate this procedure, the k_t table and two crop growth coefficient curves are given in the Appendix. A complete description of the Blaney-Criddle formula and this modification procedure, including the 19 crop coefficient curves, is given in the USDA, Soil Conservation Service, Technical Release No. 21. It is recommended that it be obtained by those desiring more detailed information. (See Bibliography)

Other Design Factors

Water supply requirements must also take into account the amount of effective rainfall, irrigation efficiency and leaching requirements.

1. Effective rainfall - that which falls during the irrigation season and useable to meet consumptive-use requirements but does not include excess water which may go into deep perculation or surface runoff. In arid or semi-arid regions, effective rainfall can usually be neglected. In humid regions an irrigation system must also be designed to meet the most severe drouth conditions which in these cases has the least known rainfall during the crop season. Local conditions should be carefully studied by the design engineer with these factors in mind.

2. Irrigation efficiency - with most sprinkler systems the water is delivered by pipe so there is no appreciable water loss in water conveyance from the source (well, ditch, stream or reservoir) to the area to be irrigated. Irrigation efficiency therefore is the field application efficiency and is expressed as the ratio (in percentage) of the amount applied to the root zone to the amount discharged by the sprinklers. This efficiency will vary from 60 to 75 percent depending on the uniformity of distribution, evaporation losses and the management of the system. Most engineers arbritrarily use an efficiency range of 65 to 70 percent for calculating water requirements, under favorable operation and management conditions. It is extremely important that the sprinkler selection and spacings be properly made (see page 26) if these efficiencies are to be achieved.

Leaching Requirements

A complete discussion of this subject is beyond the scope of this publication. There are, however, fairly simplified formulae and tables developed by the U.S. Department of Agriculture (see bibliography) which the planner can calculate leaching requirements. The engineer should obtain from his agricultural technical counter part the net amount of leaching water required after allowing for effective off season rainfall and deep perculation losses during the irrgation season. From this net figure he can calculate the gross amount to apply based on the application efficiency of the planned system to obtain both the annual volume requirement and the depth (hours of operation) to apply by the sprinkler system. For example, if a 150 mm (6") applicatic is required, and the field application efficiency is 75% then $\frac{150}{.75}$ or 200 mm (8") of leaching water is to be applied.

Fortunately there is "built in" to the sprinkler system the capacity to handle most leaching requirements, as the system is designed to handle peak moisture crop requirements and leaching can generally be done during the off season or peak use periods. For example, if the above requirement is used (200 mm) and the planned system has a capacity of applying 7.5 mm (.3") per hour, then it would require $\frac{200}{7.5}$ or about 27 hours per lateral set to apply the leaching requirements.

It should be emphasized along with the leaching requirement, that proper and adequate drainage must be provided to carry off the leaching water and deep perculation losses, otherwise water logging will occur, resulting in even more harmful conditions.

Soils

A soil survey or classification is essential and should include the following key factors:

1. Intake rates to determine the optimum rate at which the soil will absorb water.

As a guide, Table 3 lists recommended maximum sprinkler application rates for average soil, slope and cultural conditions. (See top of next page.)

The minimum application rate for most sprinklers is about .5 cm (.20") per hour to obtain good distribution efficiency when operated under favorable climatic conditions. At high temperature or wind conditions the application rate should equal the maximum rates noted in Table 3.

2. Water Holding Capacity of Soil

Various texture soils have inherent abilities to retain water. When the maximum is reached, it is called field capacity and any additional amount of irrigation (except as required for periodic leaching) is an economic loss.

Table 3. Suggested maximum application rates for sprinklers for average soil, slope and tilth*

Soil Texture and Profile	0 - 5% Slope		5 - 8% Slope		8 - 12% Slope		12 - 16% Slope	
	in/hr	cm/hr	in/hr	cm/hr	in/hr	cm/hr	in/hr	cm/hr
1. Coarse sandy soil to 2m. (6')	2.0	5.10	1.5	3.75	1.0	2.54	.50	1.27
2. Coarse sandy soils over more compact soils	1.5	3.75	1.0	2.54	.75	1.9	.40	1.02
3. Light sandy loams to 2m. (6')	1.0	2.54	.80	2.03	.60	1.5	.40	1.02
4. Light sandy loams over more compact soils	.75	1.9	.50	1.27	.40	1.02	.30	.76
5. Silt loams to 2m. (6')	.50	1.27	.40	1.02	.30	.76	.20	.51
6. Silt loams over more compact soils	.30	.76	.25	.63	.15	.38	.10	.25
7. Heavy textured clays or clay loams	.15	.38	.10	.25	.08	.20	.06	.15

*Chap VI - Part 1 - Section 6, Regional Engineering Handbook, U.S. Department of Agriculture, Soil Conservation Service.

The extraction of this moisture by the plant follows a general pattern about as follows:

40% in the upper quarter of root zone
30% in the second quarter of root zone
20% in the third quarter of root zone
10% in the fourth quarter of root zone

A general rule of thumb for agronomic crops in arid and semi-arid regions is that the moisture level within the root zone should not fall below 50% of the field capacity. It is also desirable to bring the moisture level at or near to field capacity; therefore the irrigation period and frequency are cyclic and identical.

In humid regions from an operating standpoint it is necessary to allow for rains during the irrigation period, however, the 50% limitation on soil moisture depletion should be followed for design purposes.

Tables 4 and 5 can be used in determining the field capacity of various types of soils for the effective root depths of various crops when grown in deep well drained soils.

Table 4. Range in available moisture holding capacity of soils of different texture*

	mm of water per cm. of depth	Inches of Water per foot of depth
1. Very coarse texture -- very coarse sands	.33 to .58	.40 to .70
2. Coarse texture -- coarse sands, fine sands and loamy sands	.62 to 1.05	.75 to 1.25
3. Moderately coarse texture -- sandy loams and sandy loams	1.05 to 1.46	1.25 to 1.75
4. Medium texture -- very fine sandy loams, loams and silt loams	1.25 to 1.92	1.50 to 2.30
5. Moderately fine texture -- clay loams, silty clay loams and sandy clay loams . .	1.46 to 2.10	1.75 to 2.50
6. Fine texture --sandy clays, silty clays and clays	2.10 to 2.10	1.60 to 2.50
7. Peaks and mucks	1.66 to 2.50	2.00 to 3.00

* Chapter 1 - Section 15 - Soil-Plant-Water Relationships, USDA-Soil Conservation Service.

Table 5. Depth to which crops will extract available soil moisture from deep, well-drained soils

	Depth of moisture extraction			Depth of moisture extraction	
	ft.	cm.		ft.	cm.
Alfalfa	6	180	Sugar beets	4	120
Asparagus	6	180	Sweet potatoes	4	120
Deciduous orchard	6	180	Carrots	3	90
Grapes	6	180	Eggplant	3	90
Hops	6	180	Peas	3	90
Sorghums, grains	6	180	Peppers	3	90
Sudan grass	6	180	Squash (summer)	3	90
Tomatoes	6	180	Sweet corn	3	90
Corn (field)	5	150	Table beets	3	90
Flax	5	150	Beans (bush)	2	60
Melons	5	[illegible]	Cabbage	2	60
Small grains	5	150	Pasture	2	60
Artichokes	4	120	Potatoes	2	60
Beans, lima	4	120	Spinach	2	60
Citrus orchards	4	120	Strawberries	2	60
Cotton	4	120	Lettuce	1	30
			Onions	1	30

Table 6. Peak period average daily consumptive use rates (u_p) as related to estimated actual monthly use (u_m)

Net Irrigation Application I		Computed Peak Monthly Consumptive Use Rate (u_m) in Inches 1/ *																
		4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0
Inches	Cm.	Peak Period Daily Use Rate (u_p) in Inches per Day *																
1.0	2.54	.15	.18	.20	.22	.24	.26	.28	.31	.33	.35	.37	.40	.42	.44	.46	.49	.51
1.5	3.81	.15	.17	.19	.21	.23	.25	.27	.29	.32	.34	.36	.38	.41	.43	.45	.47	.50
2.0	5.08	.15	.16	.18	.20	.23	.25	.27	.29	.31	.33	.35	.37	.39	.41	.44	.46	.48
2.5	6.35	.14	.16	.18	.20	.22	.24	.26	.28	.30	.32	.34	.36	.39	.41	.43	.45	.47
3.0	7.52	.14	.16	.18	.20	.22	.24	.26	.28	.30	.32	.34	.36	.38	.40	.42	.44	.46
3.5	8.79	.14	.16	.18	.19	.21	.23	.25	.27	.29	.31	.33	.35	.37	.39	.41	.44	.46
4.0	10.16	.14	.15	.17	.19	.21	.23	.25	.27	.29	.31	.33	.35	.37	.39	.41	.43	.45
4.5	11.43	.14	.15	.17	.19	.21	.23	.25	.27	.29	.31	.33	.35	.37	.39	.41	.43	.45
5.0	12.70	.13	.15	.17	.19	.21	.23	.25	.26	.28	.30	.32	.34	.36	.38	.40	.42	.44
5.5	13.97	.13	.15	.17	.19	.21	.22	.24	.26	.28	.30	.32	.34	.36	.38	.40	.42	.44
6.0	15.24	.13	.15	.17	.19	.20	.22	.24	.26	.28	.30	.32	.34	.36	.38	.40	.41	.43

1/ Based on the formula $u_p = 0.034\ u_m^{1.09}\ I^{-.09}$ where
u_p = Average daily peak period consumptive use in inches.
u_m = Average consumptive use for the peak month in inches.
I = Net irrigation application in inches.

*To convert to centimeters multiply by 2.54.

3. Peak period consumptive-use

The design engineer needs to know the peak daily crop use in order to determine the minimum capacity requirements for the sprinkler system. This is the period during which the weighted average daily rate of consumptive-use of the various crops grown is at a maximum. Different crops may have their peak rates of use at different times, or in some instances may not even be grown. Therefore it is important to carefully analyze the individual crop requirements.

It is preferable that local data on peak requirements be used; however, the Blaney-Criddle Formula can be used in conjunction with Table 6 in determining peak consumptive-use.

Peak Values For Preliminary Estimates

When the design engineer is called on to prepare preliminary plans prior to a detailed study and where local data are not available, the values given in Table 7 can be used, with such adjustments as deemed necessary for local weather and crop conditions. The lower values are for semi-arid climate and the higher values are for arid type climate.

It must be kept in mind that the peak requirements are for design purposes and not necessarily the critera for operating the system. The user must be guided by soil moisture and crop conditions in determining the frequency and amount of water to apply during the crop growing period. There are various instruments for determing soil moisture, however, the "feel and appearance" method is one practical way to estimate the amount of soil moisture. A discussion with illustrations of this method is contained in the Appendix.

Table 7. Peak use daily requirements
(Range in Values for Western United States)*

Crop	cm./day	inch/day	Crop	cm./day	inch/day
Alfalfa	.68 to .89	.27 to .35	Orchards (Cont.)		
Corn	.35 to .63	.14 to .25	Citrus	.33 to .53	.13 to .21
Cotton	.68 to .79	.27 to .31	Deciduous Fruits	.56	.22
Flax	.63 to .71	.25 to .28	Pasture	.74 to .81	.29 to .32
Grain	.38 to .53	.15 to .21	Potatoes	.63 to .74	.25 to .29
Grapes	.48	.19	Sugar Beets	.51 to .63	.20 to .25
Orchards			Tomatoes	.51	.20
Avocadas	.48	.19	Truck Crops	.51 to .66	.20 to .26

*NOTE: Above data from U.S.D.A., Agricultural Research Service and Soil Conservation Service. Sprinkler application rate must be based on field application efficiency.

SPRINKLER SELECTION

Primary consideration in the design of any sprinkler system is the moisture requirements of the crop and the ability of the soil to absorb and retain water. The sprinkler is the "key" as its operating characteristics under optimum pressures will determine how it will fit into the design.

Table 8, on page 27, has been prepared by the Soil Conservation Service of the U.S. Department of Agriculture. These characteristics are for U.S. sprinklers; however, those manufactured in other countries usually have similar basic characteristics and adaptability.

Distribution Pattern

The typical sprinkler has a geometric pattern of higher application near the sprinkler head and decreasing to the outer circumference. One such pattern is shown in Figure 11.

Pressure and wind markedly affects the geometric pattern of any sprinkler as shown in Figure 12. Operating at lower than recommended pressure will result in "waves" in the pattern and larger droplets as shown in Figure 13. Higher pressure over that recommended by the manufacturer also distorts the pattern and will usually result in a finer "mist" and marked drifting under wind conditions. The design engineer, therefore, should follow the manufacturer's pressure recommendations for each sprinkler to be selected. In order to smooth out the distribution it is necessary to have a generous overlap of the sprinkler throw.

Sprinkler Overlap

No specific standard has been developed; however, many studies have been made by both the manufacturer and various research institutions. General guidelines for spacing of the sprinklers representing a "cross section" of these investigations are:

1. For low to moderate pressure sprinklers---.35 to 1. kg/sq.cm. (5 to 15 psi).

a. For wind conditions to 6 km/hr (4 miles/hr) do not exceed 50% of the wetted diameter of the sprinkler for the spacing of the sprinklers on the lateral line and 65% of the wetted diameter for the distance of the lateral move to its next position.

b. For winds 6 to 15 km/hr (4 to 10 miles per hour) reduce the above percentages to not exceed 40% and 50% respectively.

2. For high pressure and giant sprinklers---4. to 7 kg/sq.cm. (60 to 100 psi).

The general recommendation is not to exceed 60% of the wetted diameter for both the lateral and move intervals in winds not to exceed 6 km/hr (4 miles/hr) and reduce to 50% if wind conditions are in the 6 to 15 km/hr range.

Table 8. Classification of sprinklers and their adaptability

Type of sprinkler	Low pressure 5-15 p.s.i. .35-1 kg/sq.cm.	Moderate pressure 15-30 p.s.i. 1-2 kg/sq.cm.	Intermediate pressure 30-60 p.s.i. 2-4 kg/sq.cm.	High pressure 50-100 p.s.i. 3.5-7 kg/sq.cm.	Hydraulic or giant 80-120 p.s.i. 5.6-8.4 kg/sq.cm.	Undertree low-angle 10-50 p.s.i. .7-3.5 kg/sq.cm.	Perforated pipe 4-20 p.s.i. .28-1.4 kg/sq.cm.
General characteristics	Special thrust springs or reaction-type arms.	Usually single-nozzle oscillating or long-arm dual-nozzle design.	Either single or dual nozzle design.	Either single or dual nozzle design.	One large nozzle with smaller supplemental nozzles to fill in pattern gaps. Small nozzle rotates the sprinkler.	Designed to keep stream trajectories below fruit and foilage by lowering the nozzle angle.	Portable irrigation pipe with lines of small perforations in upper third of pipe perimeter.
Range of wetted diameters	20 to 50 feet. 6 to 15 m.	60 to 80 feet. 18 to 24 m.	75 to 120 feet. 23 to 37 m.	110 to 230 feet. 33 to 70 m.	200 to 400 feet. 60 to 120 m.	40 to 90 feet. 12 to 27 m.	Rectangular strips 10 to 50 feet wide. 3 to 15 m.
Recommended minimum application rate	0.40 inch per hour. 1.0 cm/hr.	0.20 inch per hour. 0.50 cm/hr.	0.25 inch per hour. 0.62 cm/hr.	0.50 inch per hour. 1.25 cm/hr.	0.65 inch per hour. 1.6 cm/hr.	0.33 inch per hour. 0.83 cm/hr.	0.50 inch per hour. 1.25 cm/hr.
Jet characteristics (assuming proper pressure-nozzle size relations)	Waterdrops are large due to low pressure.	Waterdrops are fairly well broken.	Waterdrops are well broken over entire wetted diameter.	Waterdrops are well broken over entire wetted diameter.	Waterdrops are extremely well broken.	Waterdrops are fairly well broken.	Waterdrops are large due to low pressure.
Moisture distribution pattern (assuming proper spacing and pressure-nozzle size relations)	Fair	Fair to good at upper limits of pressure range.	Very good.	Good <u>except</u> where wind velocities exceed 4 miles per hour.	Acceptable in calm air. Severely distored by wind.	Fairly good. Diamond pattern recommended where laterals are spaced more than one tree interspace.	Good pattern is rectangular.
Adaptations and limitations.	Small acreages. Confined to soils with intake rates exceeding 0.50 inch per hour and to good ground cover on medium- to coarse-textured soils.	Primarily for undertree sprinkling in orchards. Can be used for field crops and vegetables.	For all field crops and most irrigable soils. Well adapted to overtree sprinkling in orchards and groves and to tobacco shades.	Same as for intermediate pressure sprinklers except where wind is excessive.	Adaptable to close-growing crops that provide a good ground cover. For rapid coverage and for odd-shaped areas. Limited to soils with high intake rates.	For all orchards or citrus groves. In orchards where wind will distort overtree sprinkler patterns. In orchards where available pressure is not sufficient for operation of overtree sprinklers.	For low-growing crops only. Unsuitable for tall crops. Limited to soils with relatively high intake rates. Best adapted to small acreages of high-value crops. Low operating pressure permits use of gravity or municipal supply.

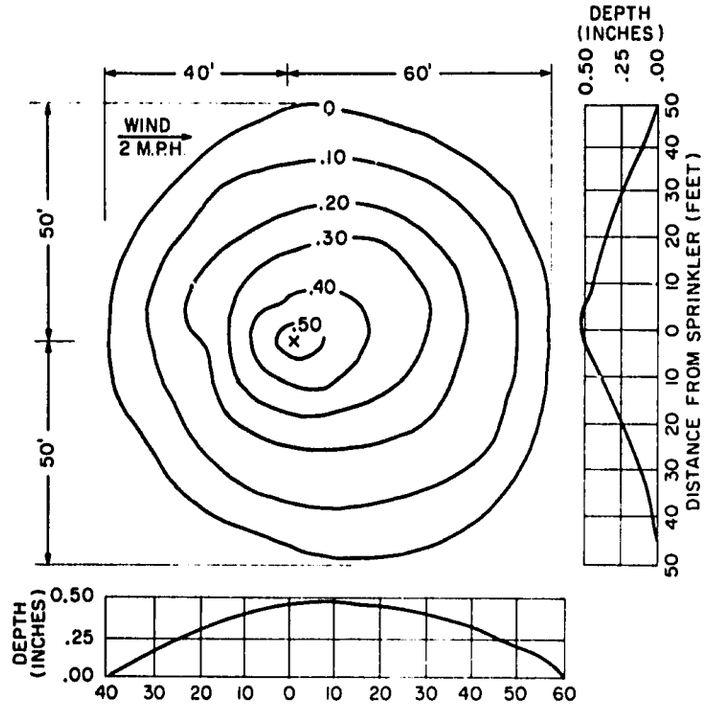


Figure 11. Distribution pattern from sprinklers operating under favorable conditions.

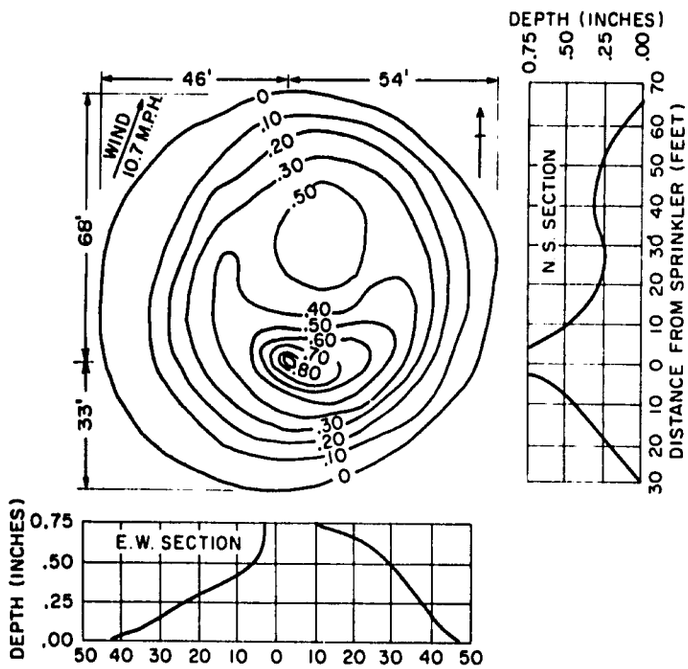
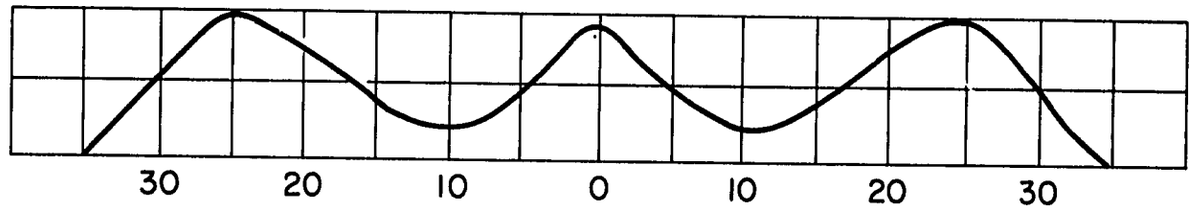
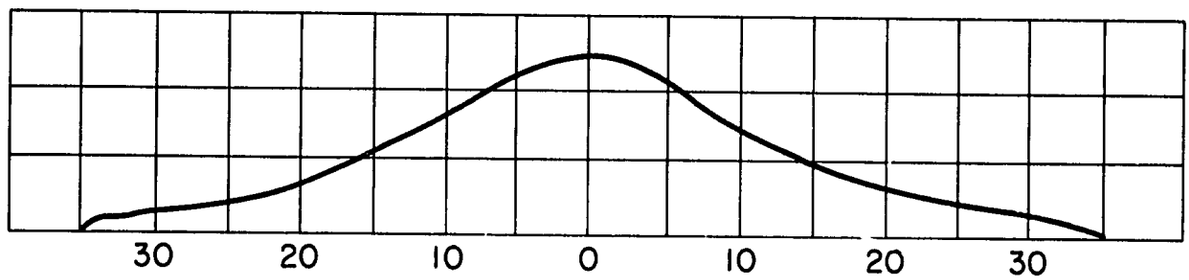


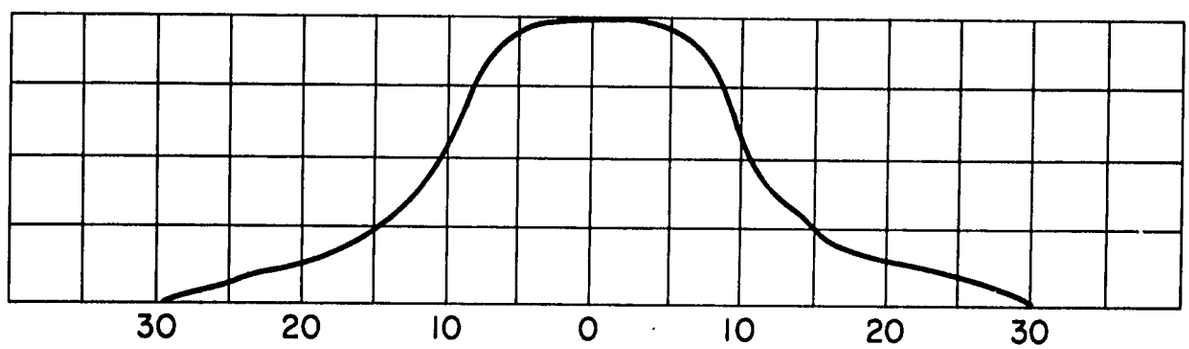
Figure 12. Effect of wind on distribution pattern



A-PRESSURE TOO LOW



B-PRESSURE SATISFACTORY



C- PRESSURE TOO HIGH

Figure 13. Effect of different pressures of typical U.S. sprinklers. Note changes in the distribution pattern. The zero position above is the sprinkler location.

Pipe Lengths

It should be mentioned here that pipe lengths for sprinkler systems are becoming generally standardized. In the United States the lateral and portable main line tubing is available in 20, 30 and 40-foot lengths; whereas in Europe there has been a tendency to standardize on 6- and 9-meter lengths. The design engineer must consider this in his design work and adapt his design to the lengths of pipe which are available. In the interest of economy, the longer pipe lengths having fewer couplers reduce the unit costs and manufacturers world-wide are encouraged to provide tubing in 6, 9 and 12 meter lengths (20', 30' and 40') particularly if lightweight tubing are used. These selections permit nearly any desirable spacing with the minimum of couplers.

Height of Sprinkler Risers

Sprinkler height is usually dictated by the crop being irrigated and also to avoid hydraulic turbulance in the riser pipe. Minimum heights is about as follows for most irrigation sprinklers:

Riser Pipe Diameter		Minimum Riser Height	
cm.	Inches	cm.	Inches
1.27	1/2	7.6	3.
1.90	3/4	15.	6.
2.54	1	30.	12.
7.6	3 (giant spks.)	90.	36.

Most crops exceed 30 cm (12") so except for clean cultivated orchards where low riser pipes are desirable for under tree sprinkling, the choice will be the minimum height to clear the crop. Although some research studies indicate additional height, 30 to 60 cm (12" to 24"), improve the sprinkler distribution efficiency there are obvious disadvantages such as wind drift and in the matter of handling the lateral line. Farmers usually prefer 45 cm to 60 cm risers (18" to 24") except for high growing crops such as cotton and corn.

Evaporation Losses When Sprinkling

Evaporation losses are made up of sprinkler spray evaporation and surface evaporation from the free water on the plant and soil. Contrary to the opinion of some, these combined losses are low during the sprinkling period. A typical farm system operating at 2.0 to 3.5 kg/cm^2 (30 to 50 design psi) has negligible losses under cool weather and low wind conditions. Even at high temperature and wind condition at 25 km/hr (15 mph) the losses over a 24 hour sprinkling period on a growing crop do not exceed 8%. On bare ground, however, the losses may be double that amount. The general conclusion therefore, is that "round the clock" or 24 hour a day operation is entirely feasible except possibly on bare ground during the hot daytime hours. It should be kept in mind that these losses do not represent the overall field efficiency which include the distribution pattern of the sprinklers and their spacing (see page 26).

AN EXAMPLE TO ILLUSTRATE METHODOLOGY OF A FARM UNIT SPRINKLER DESIGN

It must be recognized that only the principles of design can be illustrated as it is very seldom that one set of conditions will be duplicated on another farm. The author wishes to emphasize this and to again stress the importance of having at hand all the agronomic and climatological data that is possible for him to obtain prior to doing the design exercise.

For the purpose of this example a simple rectangular area was chosen with known data from a specified location.

Step 1—Inventory of resources

Location: Arid-desert type region.

Soil: Moderately coarse. Sandy loam to 2 meters with natural drainage.

Topography: As noted in sketch (Figure 14).

Water source: Stream Supply adequate for irrigation.

Water quality: Less than .5 gm/liter total desolved salts. (500 parts/million).

Power source: Electricity - 3 phase.

Crop: Alfafa - (other crops may be grown in a rotation, however, alfalfa has highest peak water requirement.)

Climate: Arid and with no effective rainfall during the peak growing period.

Wind: As shown in Figure 14.

Step 2—Water to apply each irrigation

Referring to Table 4, the total available moisture holding capacity for the soil on this farm ranges from 1.05 to 1.46 millimeters per centimeter of depth (1.25" to 1.75" per foot). Using an average value of 1.25 mm/cm (1.50"/ft.) and a moisture extraction depth of 180 cm. (6') as given in Table 5, the total available moisture is about 23 cm (9"). On the basis of not using more than 50% of this moisture, the maximum amount to be applied each irrigation is about 11.5 cm (4.5").

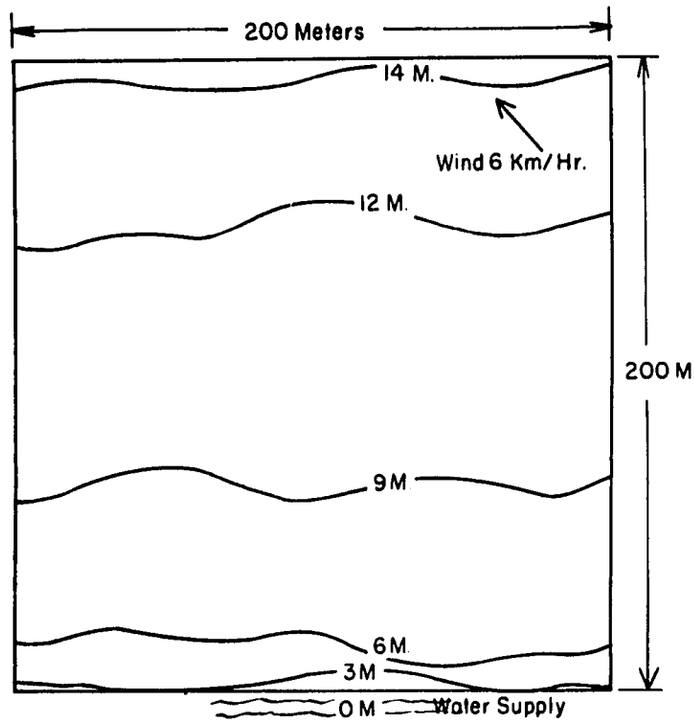


Figure 14. Dimensions and elevations of field to be irrigated.

Step 3—Shortest interval

This is the time allowable between successive irrigations, commonly called the rotation cycle, during the peak consumptive-use of the crop. Using the value of .89 cm/day (.35") from Table 7, the rotation cycle becomes $11.5/_{.89}$ or 13 days.

Step 4—Capacity of system

The pump capacity or system requirement is calculated by the equation:

Metric	English
$Q = \frac{A \times D \times 278}{F \times H \times E}$	$Q = \frac{A \times D \times 453}{F \times H \times E}$

where:

Q = Liters per second of pump	Gallons per minute of pump
A = Area in hectares	Area in acres
D = Depth application in cm.	Depth in inches
F = Irrigation interval in days	Interval in days
H = Hours per day operation	Hours operation
E = Field application efficiency (as a fraction)	Field application efficiency (as a fraction)
278 = Conversion factor	453 = Conversion factor.

On the basis of 22 hours per day operation (allowing 2 hours per day to move the laterals) and a field application efficiency of .70, the capacity required of pump is:

Metric $Q = \frac{4 \times 11.5 \times 278}{13 \times 22 \times .7} = 6.4$ lit./sec

English $Q = \frac{9.88 \times 4.5 \times 453}{13 \times 22 \times .7} = 100$ gpm

Step 5—Optimum water application rate

This will be determined by the soil type, crop cover and slope and is the application rate without puddling or surface run-off. In this example the slope is fairly uniform averaging about 5% and, as there may be periods where the crop protection will be negligible the maximum application rate (Table 3) is 1.5 cm/hr (.6"/hr). Sprinkler selection and spacing must be so as to not exceed this rate.

Step 6—Type of sprinkler to be selected

As previously discussed the sprinkler selection is the "key" and it will determine the balance of the design work. Table 8 is one guide as far as limitations and characteristics are concerned although they usually are "multiple" choices.

Most sprinkler systems are designed for "round the clock" or continuous operation which will permit the minimum size of pump, main and laterals. Lateral moves generally are on the basis of 2 or 3 moves per 24 hours for most crops; however, this will also be governed by the depth of application required and application rate.

The intermediate pressure sprinkler has been selected for this example as most nearly satisfying all the above conditions. The higher pressure sprinkler would be satisfactory; however, higher equipment and operating costs would result, and, since this is to be a hand move system, no particular advantage would accrue.

Step 7—Sprinkler spacing, nozzle discharge, and operating pressure

Engineers have different ways to solve this problem. The author uses a "back door" approach; namely, to first make an optimum arrangement on the main and lateral in respect to the topography and operation, and then by "cut and try" determine the spacing and sprinkler discharge.

In our example we know the field must be irrigated in a minimum of 13 days. If the farm operator prefers two moves (night and morning) per 24 hours, then not more than 26 moves are possible in the case of a one lateral design or 13 moves with two laterals.

Main lines should always, if possible, run up and down the predominant slope in order to provide best control of lateral pressures. Laterals should be at or near 90° angle to the main and run across the slope. Also, it is desirable to have the lateral at or near 90° to the prevailing wind. These may not be compatible in which case the slope consideration should take precedence.

We also have certain basic limitations on maximum move intervals, which for the typical intermediate pressure sprinkler is 18 meters (60') (see page 27).

Now make a trial layout of the main with the above factors in mind. In our example the location of the main would ideally be through the center of the field and with 18-meter intervals for lateral moves, there will be a total of 11 lateral sets by locating the first and last positions 9 meters (30') from the edge of the field. If 15-meter (50') move intervals were selected there would be 13 sets.

With the management plan to move the lateral twice each 24 hours the field could be covered with one lateral equal to 1/2 the width of the field, in 11 days using the 18-meter interval and in 13 days with the 15-meter interval. Thus either arrangement is satisfactory in respect to the time element.

Step 8—Number of sprinklers required

The next step is to select sprinkler spacings and test them for application rates. Here again it is necessary to establish a maximum spacing of the sprinklers on the lateral which for intermediate pressures sprinklers is generally accepted under the given wind conditions at 12 meters (40'). Closer spacings are acceptable (and preferable in more windy conditions) so we will "test out" both 9 meters (30') and 12 meters (40') sprinkler spacing. In our example this becomes 11 or 8 sprinklers respectively by locating the first and last sprinkler 5 meters from the main line and edge of field.

We therefore have 4 possible move-spacing selections: 18 x 12 meters; 18 x 9; 15 x 12; or 15 x 9. Application rates in each case is determined by the formula:

$$\text{cm. per hour} = \frac{\text{Liter/sec of Sprinkler} \times 360}{\text{spacing} \times \text{move in meters}}$$

or

$$\text{Inches per hour} = \frac{\text{GPM of Sprinkler} \times 96.3}{\text{spacing} \times \text{move in feet}}$$

In this example these become:

Move-spacing	No. Sprinklers	Sprinkler Size Lit/sec	Sprinkler Size GPM	Application Rate cm/hr	Application Rate In./hr
18 x 12 meters (60' x 40')	8	.80	12.5	1.33	.50
18 x 9 meters (60' x 30')	11	.58	9.1	1.29	.49
15 x 12 meters (50' x 40')	8	.80	12.5	1.60	.60
15 x 9 meters (50' x 30')	11	.58	9.1	1.54	.58

Referring back to step 5, we find that 1.5 cm. per hour (.6") is the maximum application rate for this soil type. All of the various selections are perhaps sufficiently close; however, a good selection would be the 18 x 9 meter arrangement as it has the advantage of a low application rate plus the fact that in windy conditions the closer sprinkler spacing on the lateral will permit more overlap and better distribution efficiency as compared to the 18 x 12 meter arrangement.

The next step is to refer to sprinkler manufacturers catalogs to select nozzles, pressures and the wetted diameters to meet these requirements. With the .58 lit./sec. sprinkler discharge (9.1 gpm.), the nozzle combination is 3/16" x 7/64" for a typical double nozzle sprinkler operating at 3.2 kg/sq.cm. (45 psi) with a wetted diameter of about 32 meters (100').

Step 9—Layout of system

We have completed the basic design and it is well to check at this time to determine if any adjustments are necessary. Listing our key data:

Water to apply -- 11.5 cm. (4.5")

Peak crop requirement -- .89 cm. per day (.35")

Maximum irrigation interval -- 13 days

Pump capacity required at assumed 70% field application efficiency -- 6.4 lit/sec or 100 gpm.

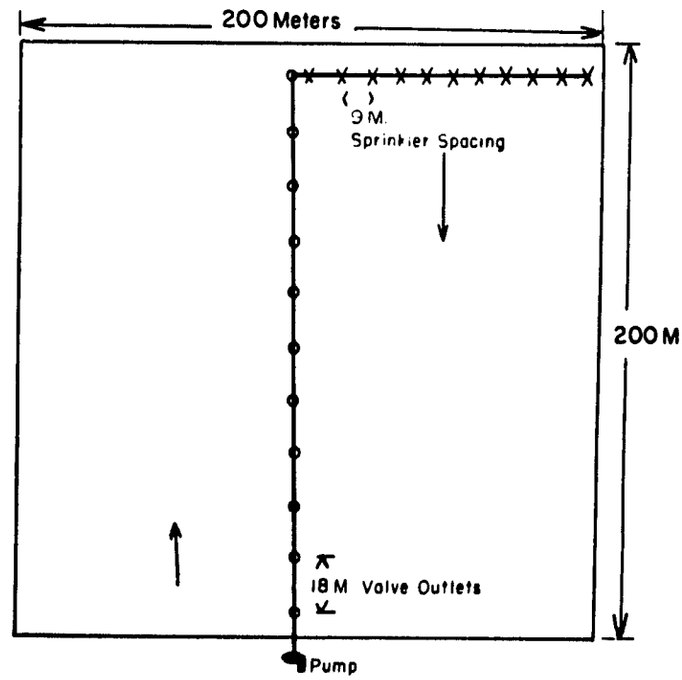


Figure 15. Layout of system.

Design:

Sprinklers spacing -- 18 x 9 meters (60' x 30')

Type of sprinkler -- Intermediate pressure

Main line -- 200 meters (660') with lateral outlet each 18 meters (60')

Lateral -- 95 meters (315') with 11 sprinklers spaced each 9 meters (30')

Sprinkler capacity -- .58 lit./sec (9.1 gpm)

Application rate -- 1.29 cm/hr (.49"/hr)

Hours per lateral set -- 11.0

Total gross application -- 14.2 cm. (5.4")

Net application (70% eff) 9.94 cm. (3.8")

Rotation -- 11 days with two lateral sets per 24 hours.

Daily equivalent moisture replacement over rotation period -- .90 cm. (.36")

Step 10—Adjustments

The above design meets all of the requirements; however, it is to be noted that the system must be operated continuously during the peak use period in order to maintain the soil moisture level.

Step 11—Selecting size of lateral

In the interest of economy and ease of handling, the minimum diameter pipe should be selected consistent with good sprinkler performance. A difference of 20 percent in pressure results in about a 10 percent difference in nozzle discharge and this maximum pressure variation between the first and last sprinkler on a lateral has been generally accepted world wide as acceptable design criteria.

There have been developed numerous pre-engineered tables, logarithmic charts, nomographs and special friction loss slide rules to expedite lateral line selection. The design engineer is encouraged to use these, however, for purpose of methodology the pipe friction loss and multiple outlet correction factor method is used herein. The step by step procedure follows:

1. Select a given size of pipe.

2. Assume the flow is through the entire length without sprinklers and from Table 9 determine the friction loss.

3. Multiply loss (2) by the correction factor (Table 10) corresponding to the number of sprinklers on the lateral.

4. To (3) add the elevation if the lateral goes uphill or subtract the drop if the lateral goes downhill.

5. Compare (4) with the allowable 20 percent loss. If it is approximately the same then your selection is correct; otherwise select another diameter pipe and repeat.

Table 9. Friction loss in feet per 100 feet in lateral line of portable aluminum pipe with couplings

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

Flow		2-inch[2]	3-inch[2]	4-inch[2]	5-inch[2]	6-inch[2]
Lit/sec	GPM	K_s = .34	K_s = .33	K_s = .32	K_s = .32	K_s = .32
1.26	20	.32				
1.89	30	2.53				
2.52	40	4.49	0.565	0.130		
3.15	50	6.85	.858	.198		
3.79	60	9.67	1.21	.280		
4.42	70	12.9	1.63	.376	0.122	
5.05	80	16.7	2.10	.484	.157	
5.68	90	20.8	2.63	.605	.196	
6.31	100	25.4	3.20	.738	.240	0.099
7.57	120		4.54	1.04	.339	.140
8.83	140		6.09	1.40	.454	.188
10.10	160		7.85	1.80	.590	.242
11.36	180		9.82	2.26	.733	.302
12.62	200		12.0	2.76	.896	.370
13.88	220		14.4	3.30	1.07	.443
15.14	240		16.9	3.90	1.26	.522
16.41	260		19.7	4.54	1.47	.608
17.67	280		22.8	5.22	1.70	.700
18.93	300		25.9	5.96	1.93	.798
20.19	320		29.3	6.74	2.18	.904
21.45	340		32.8	7.56	2.45	1.02
22.72	360		36.6	8.40	2.74	1.13
23.98	380		40.6	9.36	3.03	1.26
25.24	400		44.7	10.3	3.34	1.38
26.50	420			11.3	3.66	1.51
27.76	440			12.3	4.00	1.66
29.03	460			13.4	4.35	1.80
30.29	480			14.6	4.72	1.95
31.55	500			15.8	5.10	2.12
34.70	550			18.9	6.12	2.52
37.86	600			22.2	7.22	2.98
41.01	650			25.9	8.40	3.46
44.17	700			29.8	9.68	3.99
47.32	750			33.8	11.0	4.54
50.48	800				12.5	5.15
53.63	850				14.0	5.78
56.79	900				15.6	6.44
59.94	950				17.3	7.14
63.10	1000				19.0	7.86

[1]For 20-ft. pipe lengths, increase values in the table by 7.0 percent. For 40-ft. lengths, decrease values by 3.0 percent.

[2]Outside diamter.

Note: To convert above losses to losses in meters per 30 meters multiply by .3. To convert above losses to losses in meters per 100 meters multiply by 1.0.

Table 10. Factor (F) for computing friction loss in a line with multiple outlets

Outlets (Number)	Value of F	Outlets (Number)	Value of F
1	1.000	19	0.372
2	.634	20	.370
3	.528	21	.369
4	.480	22	.368
5	.451	23	.367
6	.433	24	.366
7	.419	25	.365
8	.410	26	.364
9	.402	27	.364
10	.396	28	.363
11	.392	29	.363
12	.388	30	.362
13	.384		
14	.381	35	.359
15	.379		
16	.377	40	.357
17	.375		
18	.373	50	.355

In our example we have selected 3.2 Kg./sq.cm (45 psi) as the average design sprinkler pressure which will be at midpoint on the lateral. A 20 percent variation is .64 Kg./sq.cm (9 psi) (from 1st to last sprinkler) or converted to elevation is 6.4 meters or 20.7'. The other conditions are 11 sprinklers each discharging 9 gpm with 95 meters or (315') of lateral. The lateral locations in this example permit some "downhill" and some level placement.

Going thru the steps:

1. Trial size selected -- 3".
2. Friction loss through line without outlets using flow of 100 gpm:

   3.20 x 3.15 = 10.08 feet or 3.05 meters.
3. Correction factor for 11 sprinklers .392

   Actual friction loss = .392 x 10.08 = 3.95' or 1.2 meters.
4. No elevation correction required.
5. Total net loss is 1.2 meters (3.95') compared to 6.4 meters (20.7') allowable.

The use of 3' pipe obviously would give excellent operation characteristics. Also if the above test were applied to 2" pipe, the net loss would be over 27'. The operator

would perhaps prefer to use all 3"; however to illustrate the selection of two pipe diameters in the lateral the following procedure is used:

1. Arbitrarily select some proportion of 3" and 2". Assume that 105' of 3" and 210' of 2" were used (32 and 63 meters):

2. Calculate the loss for the 210' of 2" lateral with 7 sprinklers and 70 gpm flow (flow of 70 gpm used as table does not give 64 gpm).

Loss = 12.9 x 2.1 x .419 = 11.3' or 3.45 meters

3. Assume all of flow (100 gpm) was for the entire length (315') using 3" pipe and the 11 sprinklers.

Loss = 3.20 x 3.15 x .392 = 4' or 1.2 meters

4. Assume the flow (70 gpm) of the 2" section (210') with 7 sprinklers was in in the larger diameter (3") pipe.

Loss = 1.63 x 2.1 x .419 = 1.44' or .44 meters

5. Actual total lateral loss is the sum of items (2) + (3) minus item (4) or 11.3' + 4' -1.44' = 13.86' or rounded at 14' or 4.3 meters.

From the above calculation it is seen that a slightly higher proportion of 2" pipe could be used. From a practical operating standpoint, however, it is believed for this short lateral, one diameter (3") would be more desirable as there would not be an appreciable saving in first cost and the convenience of handling only one size lateral would soon offset the slightly higher first cost, also would permit expansion to longer laterals if the irrigated area was increased. For systems requiring long laterals two sizes are sometimes justified; however, most designers prefer to maintain one diameter whenever possible.

Step 12—Pressure required at lateral

Thus far only the midway or "average design pressure" has been noted. The friction loss along a lateral of uniform size decreases rapidly with 3/4 of the total loss occurring in the first half of the line. To calculate the end sprinkler pressure subtract the pressure equivalent of 1/4 of the lateral loss from the average design pressure, and add the pressure equivalent of 3/4 of the lateral loss to the average design pressure to obtain the pressure at the first sprinkler. In our example, if all 3" lateral is used, with 3.2 Kg./sq.cm (45 psi) average design pressure, the end sprinkler would operate at about 3 Kg./sq.cm (44.5 psi) and the beginning sprinkler at about 3.25 Kg./sq.cm (46.3 psi). For all practical purposes there would be equal pressures along the lateral. Pressure increase to compensate for the sprinkler riser pipe will be taken into account later in calculating the system design pressure.

Step 13—Determine required size of main line pipe

In contrast to lateral design there are no specific standards as to the amount allowable for main line pipe losses. Here it is a question of having a "reasonable" loss dictated by either the economics in first cost of the pipe or sometimes in pump-power unit selection. Designers usually consider as "reasonable" a mainline

Table 11. 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		3-inch[2]	4-inch[2]	5-inch[2]	6-inch[2]	7-inch[2]	8-inch[2]	10-inch[2]
Lit./Sec	GPM	(2.914)	(3.906)	(4.896)	(5.884)	(6.872)	(7.856)	(9.818)
2.52	40	0.658	0.157					
3.15	50	1.006	.239					
3.79	60	1.423	.339					
4.42	70	1.906	.449	0.150				
5.05	80	2.457	.584	.193				
5.68	90	3.073	.731	.242				
6.31	100	3.754	.893	.295	0.120			
7.57	120	5.307	1.263	.417	.170			
8.83	140	7.113	1.693	.560	.227			
10.10	160	9.169	2.182	.721	.293			
11.36	180	11.47	2.729	.967	.366			
12.62	200	14.01	3.333	1.102	.448	0.209		
13.88	220	16.79	3.996	1.321	.537	.251		
15.14	240	19.81	4.713	1.558	.633	.296		
16.41	260	23.06	5.488	1.814	.737	.344		
17.67	280	26.55	6.316	2.089	.849	.397		
18.93	300	30.27	7.203	2.381	.967	.452	0.235	
20.19	320	34.22	8.142	2.692	1.094	.511	.265	
21.45	340	38.39	9.137	3.020	1.227	.573	.298	
22.72	360	42.80	10.18	3.366	1.368	.639	.332	
23.98	380	47.43	11.29	3.731	1.516	.708	.368	
25.24	400	52.28	12.44	4.113	1.671	.781	.399	0.136
26.50	420		13.65	4.513	1.833	.857	.445	.149
27.76	440		14.57	4.930	1.988	.936	.486	.163
29.03	460		16.23	5.364	2.179	1.019	.529	.177
30.29	480		17.59	5.815	2.363	1.104	.573	.192
31.55	500		19.01	6.284	2.554	1.193	.620	.208
34.70	550		22.79	7.532	3.060	1.430	.742	.249
37.86	600		26.88	8.886	3.611	1.687	.876	.294
41.01	650		31.30	10.35	4.204	1.965	1.020	.342
44.17	700		36.03	11.91	4.839	2.262	1.174	.394
47.32	750		41.08	13.58	5.517	2.520	1.339	.449
50.48	800			15.35	6.237	2.915	1.513	.507
53.63	850			17.22	6.999	3.271	1.698	.569
56.79	900			19.20	7.801	3.646	1.893	.635
59.94	950			21.28	8.645	4.041	2.097	.703
63.10	1000			23.45	9.530	4.454	2.312	.775
69.49	1100			28.11	11.42	5.338	2.771	.929
75.72	1200			31.75	13.58	6.298	3.269	1.096
82.03	1300				15.69	7.333	3.806	1.277
88.34	1400				18.06	8.441	4.382	1.470
94.65	1500				20.59	9.624	4.996	1.675
101.0	1600				23.28	10.88	5.648	1.894
107.3	1700				26.12	12.21	6.337	2.125
114.0	1800					18.61	7.064	2.369
120.0	1900					15.08	7.829	2.625
126.0	2000					16.62	8.630	2.894

[1]Where 20-ft. (6 m.) sections of pipe are used, increase values shown in the table by 7.0 percent. Where 40-ft. (12 m.) sections of pipe are used, decrease values shown in the table by 3.0 percent.

[2]Outside diameter, inside diameter in parentheses.

Note: To convert loss in feet per 100 feet to loss in meters per 100 meters, multiply above losses by 1.0.

loss of about 3 meters (10') for small systems and up to about 12 meters (40') for large systems. Also when the system is "powered" by gravity-fall to select sizes to permit proper pressure for the sprinklers.

In our example, the main line is about 200 meters (660') with a flow of 6.4 lit./sec (100 gpm). If 3" aluminum pipe (Table 11) were used there would be a total maximum loss of about 7.6 meters (25') and with 4" pipe a loss of 1.8 meters (5.9'). It would be logical to use 4" as it would reduce the pressure requirement by about 8 psi $\left(\frac{25' - 5.9'}{2.31}\right)$ and the saving in power would soon pay for the larger size pipe.

The ultimate objective is to arrive at a selection that results in the lowest annual water-application cost. Various methods and formulae have been evolved to arrive at an "economic-balance"; however, for the purpose of this publication the following guidelines are suggested:

1. Prepare a flow diagram, locating the main line and the position of the lateral line (or lateral lines) where the "peak" friction loss will occur.

2. Note on this diagram the flow in each section of the main line.

3. Calculate the friction loss in each section of the main line where there are changes in flow. Assumed pipe sizes will be used, starting with the larger size at pump and usually changing pipe sizes where there is either a decrease in flow (by sub-main take off or lateral) or in case of a long single main line at some point to keep the friction loss to a reasonable figure.

4. Calculate the total dynamic head which includes the total losses of the system, the peak pressure requirement and the elevation difference from the water level to the high point in the field.

5. Refer to your pump-power unit catalogues and pump curves and determine the size of pump and power unit required. At this point you may wish to reexamine your pipe selection if the T.D.H. (total dynamic head) is "between" two pump-power sizes. Perhaps by reducing the mainline friction loss by 10 to 20%, you can safely use a smaller size unit, or conversely you may find you have more reserve power than needed and perhaps a change to a slightly higher friction loss can be made.

Step 14—Economy of pipe selected

To make an economic analysis it is necessary to consider not only the pipe sizes but also the particular type of main line pipe to use (steel, aluminum, plastic, pressure type concrete or cement-asbestos) and whether it is to be surface or buried, also the outlet valves and other required fittings. The design engineer should have at hand current price lists of available materials. He should also know the "future" of the planned system, whether the size of the irrigated area is to be increased in the foreseeable future, if the cropping plan may be changed later that will affect the decision of surface or buried lines, etc. Once these data and information are obtained and carefully analyzed the mainline and other components can be established and the economics of the chosen system can be determined.

Step 15—Determine operating conditions

In order to determine the size of the pumping unit, list the maximum operating conditions. For our example these are:

		English	Metric
1.	Pump capacity	100 GPM	6.4 lit. sec.
2.	Minimum lateral pressure (46.5 psi at mainline)	107 feet	33. meters
3.	Height of sprinkler riser (for alfalfa)	2 feet	.6 meters
4.	Maximum mainline loss	6 feet	1.8 meters
5.	Elevation-water source to high point	46 feet	14. meters
6.	Minor losses (elbows, valves, etc.) (est.)	10 feet	3. meters
	Total dynamic head	171 feet	52.4 meters

On large systems where conditions vary considerably during the season such as operation of fewer than the maximum laterals over extended periods this should be noted; however, in any case the above maximum conditions will determine the size of the unit or units.

Step 16—Pump and power unit selection

It is assumed that the design engineer has at hand the performance characteristic of pumps and power units. The selection of the pumping unit then becomes a matter of matching the unit to the conditions as previously determined.

Pumps and power unit for sprinkler systems should be analyzed from standpoint of (1) meeting the operating conditions, (2) comparative fuel costs where there is a choice of power units, (3) availability of service and repair parts. A competent pump engineer should be consulted if the designer hasn't previous experience in this field.

The pump engineer should visit the site or have a complete understanding of the following:

1. Is pumping unit to be in a permanent location or is it to be portable?

2. The maximum suction lift to pump and fluctuation of water level.

3. If water source is from a dug or cased tube well, the well test performance data, and physical data on construction.

4. Chemical quality of water and if water contains abrasives or debris that would be harmful to pump and system.

5. Altitude and general temperature data during operating season.

6. Power sources and fuel costs.

7. Approximate hours of operation per year.

8. Minimum and maximum head-capacity requirements and other data listed under step 15.

9. Provisions in system design for check, discharge, and air control valves (pump engineer should list his requirements). See Appendix page 83 for recommendations for valves and controls.

10. Future plans for expansion of system.

The system designer may want some general preliminary data on the power requirements. The following formule are useful in making these calculations.

English

$$\text{Water Horse Power} = \frac{\text{gpm x TDH}}{3960}$$

$$\text{Brake Horse Power} = \frac{\text{WHP}}{\text{Eff.}}$$

$$\text{BHP} = \frac{\text{gpm x TDH}}{3960 \text{ x Eff.}}$$

TDH - is total Dynamic Head in feet.
Eff. - Efficiency of pump at those operating conditions expressed as a decimal.
BHP - is the power required by the pump but does not include the power losses in the motor or drive.

Metric

$$\text{WHP} = \frac{\text{Q x TDH}}{75}$$

or

$$\text{BHP} = \frac{\text{Q x TDH}}{75 \text{ x Eff.}}$$

Where Q = Liters/Sec pump discharge

TDH = Total dynamic head in meters

Eff. = Pump efficiency

(Actually 1 English h.p. = 1.014 metric h.p., however, for estimation purposes they can be used interchangeably)

Step 17—Cost estimate

Now that the system has been designed the design engineer can prepare his cost estimate. The estimate should be broken down in sufficient detail to enable the later preparation of the overall economic analysis of the project. Suggested itemized components are:

Item	Quantity and Unit	Unit Cost	Total
1. Well Unit			
2. Pumphouse			
3. Power Unit			
4. Pump Unit			
5. Mainline complete			
6. Lateral Line Complete			
7. Sprinklers and Risers			
8. Special Equipment (list)			
9. Cash Outlay for Installation			
10. Farm Costs:			
Labor			
Tractor			
Other			
TOTAL Farm Costs			
11. Other Costs (list)			
TOTAL Cost of System _____			

Step 18—Plans -- schedules - - instructions

Following the decision to proceed (which will no doubt depend upon the economic analysis and financing arrangements) the final step will be to assemble the pertinent information either in the form of plans and specifications for bid purposes or in a form for the farmer to secure quotations from reliable dealers.

COST FACTORS

As an initial step in making an overall economic appraisal of an irrigation project, the design engineer should assemble the principal data in a form which will give a clear picture of the annual fixed and annual operating and maintenance costs.

A suggested format for compiling these data is given in the Appendix. To arrive at these costs it is necessary to establish depreciation schedules and estimates of the operation and maintenance costs. It must be recognized that only generalized data can be given as they will vary by climatic zones, extent of use, and the care of the equipment by the operator. The data given below are compiled from U.S. sources

(principally from the U.S. Department of Agriculture, Soil Conversation Service) and the design engineer should make adjustments to meet the local conditions.

Depreciation Factors

1.	Water supply	
	a. Well and casing	20 years
	b. Housing	20 years
	c. Reservoir -- years before silting up	
	d. Farm ditches -- annual maintenance	
2.	Pump, turbine	
	a. Bowl (estimated 50% of pump cost)	16,000 hours or 8 years
	b. Column	32,000 hours or 16 years
3.	Pump, centrifugal	32,000 hours or 16 years
4.	Power transmission	
	a. Gear head	30,000 hours or 15 years
	b. V Belts	6,000 hours or 3 years
	c. Flat belt, rubber, fabric	10,000 hours or 5 years
	d. Flat belt, leather	20,000 hours or 10 years
5.	Electric motors	50,000 hours or 25 years
6.	Diesel engines	28,000 hours or 14 years
7.	Gasoline or distillate engines	
	a. Air cooled	8,000 hours or 4 years
	b. Water cooled	18,000 hours or 9 years
8.	Propane engines	28,000 hours or 14 years
9.	Pipe	
	a. Heavy -- water works class	40 years
	b. Steel, coated, underground	20 years
	c. Steel, coated, surface	10 years
	d. Aluminum, (main and laterals)	15 years
10.	Sprinkler heads	8 years
11.	Misc. fittings (valves, couplers, elbows, etc.)	15 years

Annual Maintenance and Repair

1. Pump
   a. Turbine -- estimated at one half its cost divided by estimated life.
   b. Centrifugal -- estimated at full cost divided by estimate life.
2. Pump shelter -- depends on materials but is assumed to be minor.
3. Engines
   a. Electric motor — $3 year per water horse power (W.H.P.)
   b. Gasoline or distillate — $.00175 per W.H.P. hours of operation
   c. Diesel — $.0021 per W.H.P. hours of operation
4. Pipe, sprinklers, valves
   a. Buried pipe -- considered minor
   b. Surface pipe, sprinklers, valves varies widely depending on care but can be estimated at 1/2 to 2% of first cost.

Annual Operation Costs

1. Lubrication, oil, grease
   a. Electric motor -- negligible
   b. Internal combustion per 1000 hours operation

	Oil	Grease
(1) Gasoline, distillate	1 gal.	$.01
(2) Diesel	1 gal.	.01
(3) LPG or Natural	.3 gal.	.01

2. Fuel
   a. Electric -- obtain rate from power utility
   b. Internal combustion - when fuel consumption curves or specific data not available use these average consumption data (per b.h.p. hour)

(1) Gasoline	1/8 gal. for air cooled or 1/10 gal. for water cooled engines
(2) Diesel - high speed	1/12 gal.
(3) Propane	1/7 gal.
(4) Natural gas	Depending on BTU content but can be estimated to be 10 cu. feet.

3. Labor, pump

   a. Attendant at pumping plant (hours)

      (1) Permanent installation, electric, natural gas, or diesel with large fuel tank -- 3% of operating time

      (2) Gasoline, distillate, permanent -- 5%

      (3) Movable installation -- 10%

4. Labor, for moving laterals

   This is a variable depending on type of system used, and the crop. For hand move systems in low growing crops and orchards the moving of the lateral will require approximately 1.25 to 1.5 man hours per hectare (.5 to .6 man hours per acre). For high growing crops such as corn and sugar cane it could be double this time.

   Other field labor to be included is the time for moving portable main lines and for labor at beginning of season to set up the equipment and at end of season for dismantling and storing the equipment. These costs will need to be estimated by the Engineer based on the specific equipment used.

ECONOMIC FEASIBILITY

The economic feasibility of any irrigation project requires studies of the agricultural production and costs without irrigation and the expected results with irrigation. This phase is not within the scope of this publication, however, the cost data supplied by the design engineer is the "grass roots" for these subsequent studies and should provide a basis for a logical decision as to the economic viability of the proposed installation.

OPERATION AND CARE OF SYSTEM

In addition to the maintenance of the pumping plant which is standard for any pump irrigation system the following additional suggestions are given for the operation of a sprinkler system.

1. Protect against debris getting into the main and lateral. This is important as a "plugged" nozzle is not only aggravating but can materially affect application efficiency. This can be accomplished by: (a) screening at the suction inlet to screen out any foreign material that would plug the smallest nozzle diameter, (b) in starting up the system, flush out the main line prior to opening the lateral valve, and (c) flush out the lateral on every move. Lateral flushing can be done by having a reduced flow in the lateral as it is being connected.

2. Mark the lateral line location. A flag or a marker at the end of each lateral location is recommended to maintain a uniform spacing of the lateral. It is easy to do and is in the interest of uniformity of distribution.

3. Alternate the lateral location. This is particularly important where windy conditions exist. On alternate moves, use an elbow and a length of pipe equal to one half of the move interval so that the lateral will be set half way between the original location.

4. Use a pitot tube-pressure gage (see page 12). This is a simple and inexpensive method of checking sprinkler pressures. This assembly can be purchased from most sprinkler suppliers and facilitates periodic checks of the system operation. Visual observation is not always reliable. A decrease of pressure might mean pump or suction line blockage, also on multi-line operation a balancing out of pressures is important.

5. Chart out lateral moves. A new operator should be informed on the "routing" of the laterals to avoid "crossing over" or concentrating laterals.

6. Be careful with sprinklers and pipe. The life of sprinklers and pipe can be materially lengthened by simple precautions in their care. Pipe trailers are recommended. Storage of the portable pipe or racks during the off season, with the sprinklers and risers removed, will also lengthen their life.

7. Inspect regularly and repair or replace broken or damaged gaskets, sprinklers and valves. A reasonable supply of repair parts should be maintained during the irrigation season and a thorough inspection made prior to storage for repairs during the off season.

8. If the system is used for applying fertilizer, be sure the entire pipe line and sprinklers are thoroughly flushed immediately after the application.

9. All buried or permanently laid lines are to be drained at end of season even in areas where freezing does not occur. These simple precautions will add many years to the life of the equipment and also prevent costly breakdowns during the irrigating season.

OTHER FARM APPLICATIONS

Generally speaking a farm sprinkler system is designed for a specific area and cannot be "spared" for other applications unless they occur during the off irrigation season. For this reason only one other application; namely, fertilizer application, is described. Other agricultural applications such as frost protection or reduction of temperatures for certain crops require special designs and application techniques and is not within the scope or purpose of this publication.

FERTILIZER APPLICATION

Most readily soluble fertilizers can be easily injected into the sprinkler system and evenly applied. Commercial applicators are available and "home made" units can be constructed. Sketches of injection devices at the pump are shown in the Appendix.

The amount to apply for a given length lateral is easily calculated. For example, if the lateral move is in 18 meters (60') intervals and the length of lateral coverage is 100 meters (330') the area is:

Metric	$\frac{18 \times 100}{10,000}$	or	.18 hectare
English	$\frac{60 \times 330}{43,560}$	or	.45 acres

This area times the desired rate of application will determine the amount to inject for each lateral move. For example, if the desired rate is 110 kilograms per hectare (100 lbs. per acre) the quantity of fertilizer for each lateral application becomes:

Metric	.18 x 110	or about 20 kg.	
English	.45 x 100	or	45 lbs.

The time and rate to apply the "solution" is important. Most authorities recommend that (1) the soil and foilage be first thoroughly wetted for at least 30 minutes to one hour prior to the injection and (2) the application of the fertilizer solution be regulated over a period from 30 minutes to one hour and (3) to be followed with a "clear water" irrigation for 30 minutes to 1-1/2 hours depending on the crop to thoroughly wash all the fertilizer off of the foliage and to place the fertilizer in the principal root zone. Commercial applicators come with specific instructions for their use.

SUMMARY

GENERAL SUGGESTIONS FOR THE DESIGN ENGINEER

1. Develop and maintain a reference file of key engineering and agricultural publications on irrigation. Study and develop a working knowledge of all methods of irrigation, their relative advantages and disadvantages, costs, and adaptation to local conditions.

2. Become fully familiar with country based research findings on irrigation and crop requirements.

3. Develop and maintain a file of current commercial publications on irrigation equipment.

4. Obtain first hand or "practical" experience in operating a sprinkler system; visit as many installations as possible and talk to the users and thus obtain practical ideas useful in design work.

5. A sprinkler system is costly, yet do not sacrifice labor saving or control items to economize on first cost. The use of valve-tee controls on the main-line and extra lateral pipe to make offset locations are examples of the "little things" which make for convenience, labor saving and improved efficiency.

6. Visit the location prior to the design work, talk to the prespective user and obtain data on winds, water supply, future plans for crops, expansion, etc. Many times this first hand information will affect the final design and will avoid costly changes after the system is installed.

7. Go over the design with the prospective user, explain the reasons for the design and obtain "his ideas" and concurrence.

8. Follow-up after the installation is completed to check proper installation and operation.

9. Maintain a file of completed installation designs, and if possible a continued yearly record of operation data for future reference.

10. Cooperate with your technical counterparts on meetings, demonstrations, etc., in order to widen your own experience and knowledge.

BIBLIOGRAPHY

1. U.S. Department of Agriculture; Soil Conservation Service

   a. Section 15, Chapter 3 - Planning For Irrigation Systems -- Price $.45

   b. Section 15, Chapter 1 - Soil-Plant-Water Relationships -- Price $.45

   c. Section 15, Chapter 8 - Irrigation Pumping Plants -- Price $.45

   d. Section 15, Chapter 11 - Sprinkler Irrigation -- Price $.55

   e. Technical Release No. 21 - Irrigation Water Requirements

2. U.S. Department of Agriculture; Agriculture Research Service

   a. Determining Consumptive Use and Irrigation Water Requirements, Technical Bulletin 1275 Price $.25

   b. Salt Balance and Leaching Requirements in Irrigated Lands (prepared in Cooperation with U.S. Department of the Interior) Price $.25

   Note: Above publications can be secured from the U.S. Government Printing Office, Washington, D.C. 20402

3. Sprinkler Irrigation Association: Sprinkler Irrigation (377 pages) - 2nd Edition Price $9.00

   Write - Sprinkler Irrigation Association, 1028 Connecticut Ave., Washington, D.C. 20036

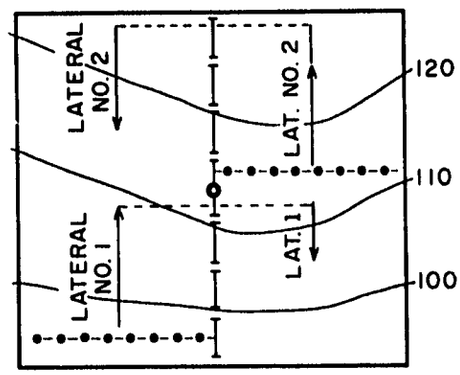
4. Rain Bird Sprinkler Mfg. Company; Glendora California, 91740 - Sprinkler Irrigation Handbook (7th Edition)

5. Benefit-Cost Evaluations as Applied to AID Financed Water or Related Land Use Projects. Manual Order 1221.3. Can be secured from Department of State, Agency for International Development, Office of Engineering, Washington, D.C. 20523

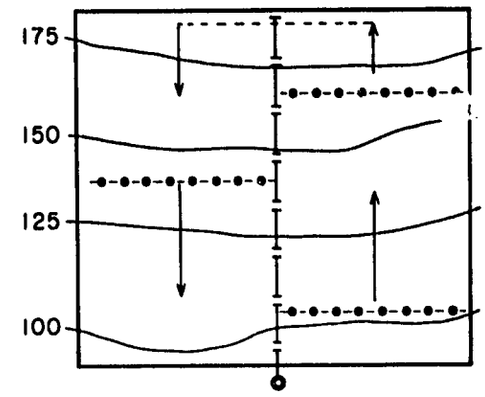
6. Irrigation Handbook; W.R. Ames Company, 1001 Dempsey Road, Milpitas, California, 95035 -- Price $5.00 including periodic loose leaf inserts on new data.

7. Sprinkler Irrigation - Agricultural Development Paper No. 88. By Food and Agriculture Organization of the United Nations -- $3.50 or 28 Shillings. To be printed in English, Spanish and French and available by the end of 1968. For U.S. purchase: National Agency for International Publications, 317 E. 24th Street, New York, N.Y. 10016. For balance of world write Food and Agricultural Organization of United Nations, Via delle Therme di Caracalla, Rome, Italy.

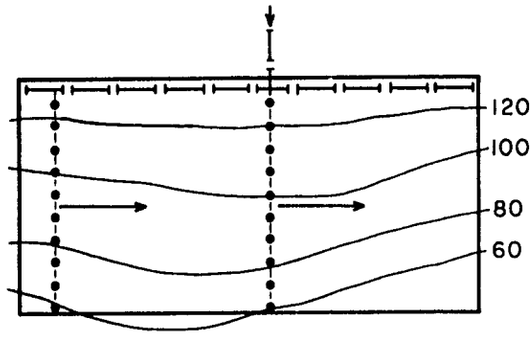
APPENDIX



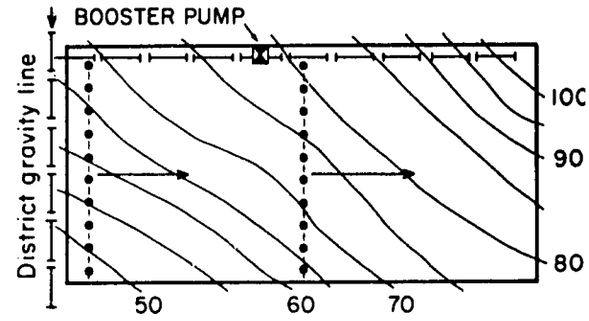
A- Layout on moderate, uniform slopes with water supply at center.



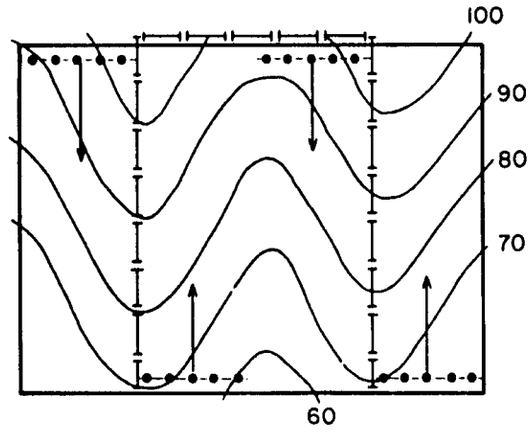
B- Layout illustrating use of odd number of laterals to provide required number of operating sprinklers.



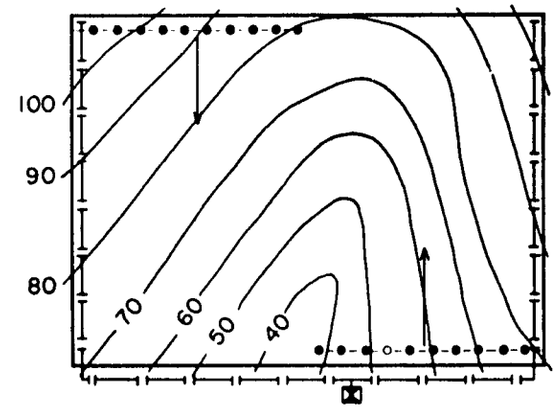
C- Layout with gravity pressure where pressure gain approximates friction loss and allows running lateral downhill.



D- Layout illustrating area where laterals have to be laid downslope to avoid wide pressure variation caused by running laterals upslope



E- Layout with two main lines on ridges to avoid running laterals uphill.



F- Layout with two main lines on the sides of the area to avoid running the laterals uphill.

Figure 16. Layouts of sprinkler systems showing effect of topography.

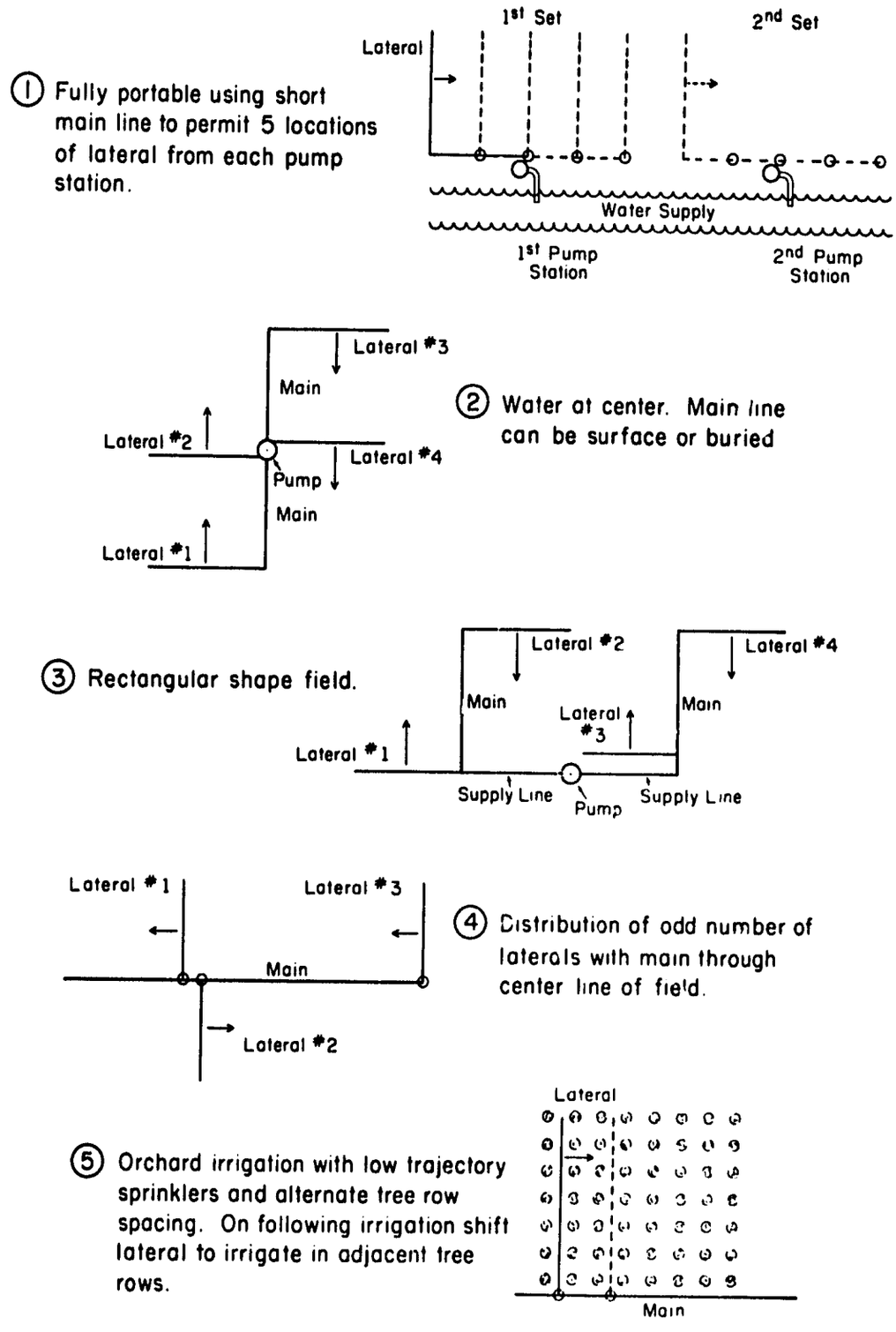


Figure 17. Typical sprinkler layouts.

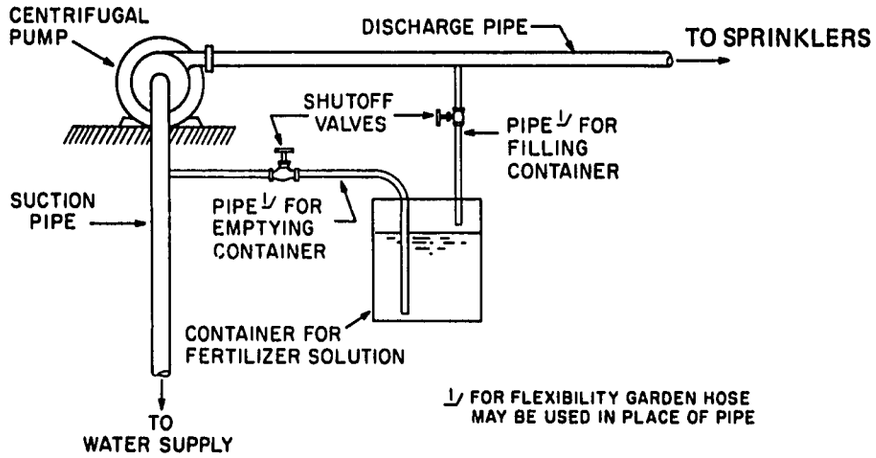


Figure 18. Method for adding fertilizers in solution to centrifugal pump system.

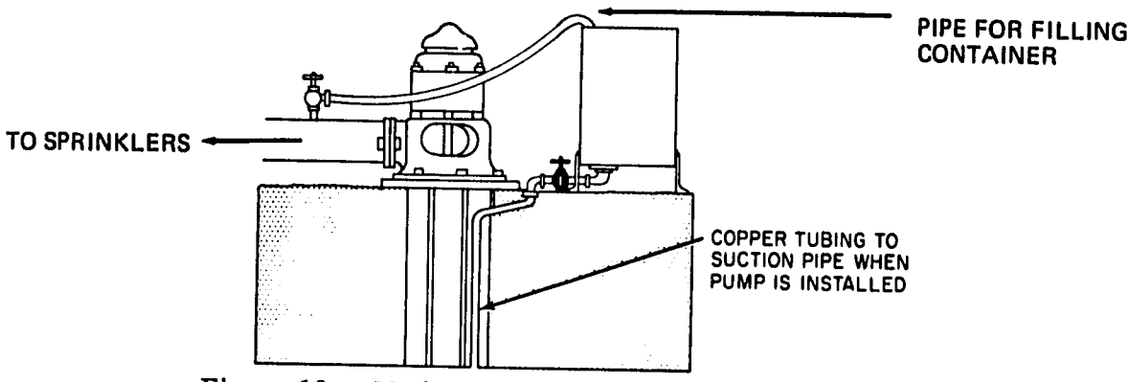


Figure 19. Method for adding fertilizers in solution to a deep well turbine system.

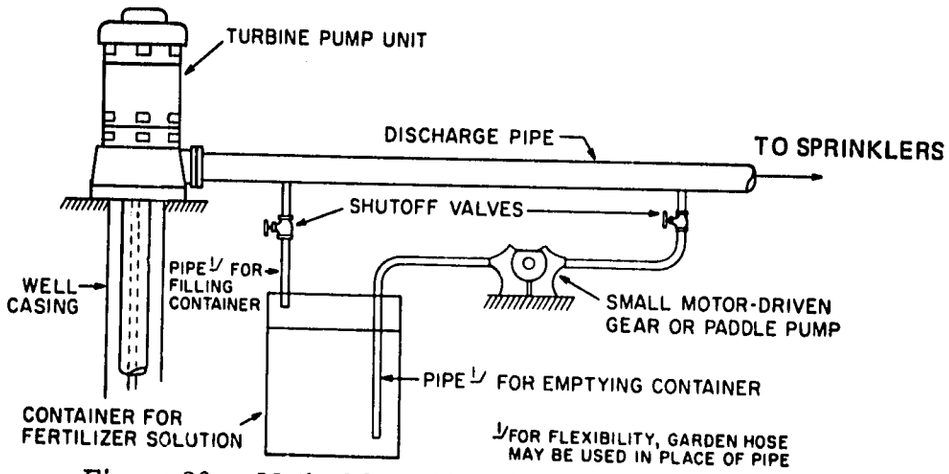


Figure 20. Method for adding fertilizers to a turbine using a small gear or paddle pump.

Table 12. Maximum number of sprinklers per line for given sprinkler spacings and discharge rates

Pipe Size	Sprinkler Spacing Feet	Sprinkler Spacing Meters	Liters per second per sprinkler																					
			.16	.19	.22	.25	.28	.32	.35	.38	.41	.44	.47	.50	.54	.57	.60	.63	.66	.70	.73	.76	.79	.82
			Gallons per minute per sprinkler																					
			2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10	10½	11	11½	12	12½	13
2" 5 cm.	20	6	22	20	18	17	16	14	14	13	13	12	11	11	10	10	10	10	9	9	9	9	8	8
	30	9	19	17	15	15	13	12	12	11	11	10	10	9	9	9	9	8	8	8	8	7	7	7
	40	12	17	15	14	13	12	11	10	10	10	9	9	8	8	8	8	7	7	7	7	6	6	6
3" 7.5 cm.	20	6	46	41	37	36	33	31	29	27	27	26	25	24	23	22	22	21	20	20	19	19	18	18
	30	9	40	36	32	31	29	27	25	24	24	22	21	20	19	19	19	18	17	17	16	16	15	15
	40	12	36	32	29	28	26	24	22	21	21	20	19	18	17	17	17	16	16	15	14	14	14	13
4" 10 cm.	20	6	75	67	61	59	54	51	48	45	45	43	41	40	38	37	37	36	34	33	32	32	31	30
	30	9	65	58	53	52	48	44	42	40	39	38	36	34	33	32	32	31	30	29	28	27	26	26
	40	12	59	53	48	46	43	40	38	36	36	34	32	31	30	29	29	28	27	26	25	25	24	23
5" 12.5 cm.	20	6	113	98	88	85	80	74	70	66	65	63	60	58	56	54	54	52	51	49	48	46	45	44
	30	9	96	85	77	75	69	64	61	58	57	54	52	50	48	47	47	45	44	43	42	40	39	38
	40	12	86	77	70	67	62	59	55	52	52	50	48	46	44	42	42	41	40	39	38	37	36	34
6" 15 cm.	20	6	195	150	125	120	108	100	94	88	88	84	80	77	74	72	72	70	67	65	63	62	60	59
	30	9	144	119	104	100	93	87	82	77	76	73	70	66	64	62	62	60	59	57	56	54	52	51
	40	12	120	104	93	90	84	78	74	70	69	65	63	61	58	56	56	55	54	52	50	49	48	46
Operating Pressure			30 psi 2.1 kg/cm^2			35 psi 2.45 kg/cm^2					40 psi 2.8 kg/cm^2						45 psi 3.15 kg/cm^2							

Note: Table is based on loss of 20% of operating pressure.

Table 13. Friction loss in new iron or steel pipe in feet per 100 feet*

Flow		Nominal inside diameter of pipe						
Lit./sec	GPM	3 in.	4 in.	5 in.	6 in.	8 in.	10 in.	12 in.
1.26	20	0.16						
1.58	25	0.24						
1.89	30	0.34						
2.21	35	0.45						
2.54	40	0.58	0.16					
2.84	45	0.72	0.20					
3.15	50	0.88	0.24					
3.47	55	1.04	0.29					
3.79	60	1.23	0.34					
4.42	70	1.63	0.45	0.15				
5.05	80	2.09	0.57	0.19				
5.68	90	2.60	0.71	0.23				
6.31	100	3.16	0.86	0.28				
7.57	120	4.43	1.21	0.39	0.16			
8.83	140	5.89	1.61	0.52	0.21			
10.10	160	7.55	2.07	0.67	0.27			
11.36	180	9.38	2.57	0.83	0.34			
12.62	200	11.4	3.12	1.01	0.41			
15.78	250	17.2	4.72	1.53	0.63	0.16		
18.93	300	24.2	6.61	2.15	0.88	0.21		
22.08	350		8.80	2.86	1.17	0.29		
25.24	400		11.3	3.66	1.50	0.36		
28.39	450		14.0	4.56	1.86	0.45	0.16	
31.55	500		17.0	5.54	2.26	0.55	0.19	
34.70	550		20.3	6.61	2.70	0.66	0.23	
37.86	600			7.75	3.17	0.78	0.27	
44.17	700			10.3	4.21	1.03	0.35	0.14
50.48	800			13.2	5.40	1.34	0.45	0.18
56.79	900			16.4	6.71	1.66	0.56	0.23
63.10	1000			20.0	8.16	2.02	0.69	0.28
75.72	1200					2.79	0.95	0.39
88.34	1400					3.72	1.27	0.53
101.	1600					4.74	1.62	0.67
114.	1800						2.01	0.83
126	2000						2.43	1.02

*Based on Williams and Hazen formula with C = 120.

Note: To convert to meters loss per 100 meters, multiply by 1.0.

Table 14. Friction loss in feet per 100 feet in main lines of welded steel pipe 15 years old*

(Based on Scobey's formula--K_s = .36)

Flow		4-inch[1]			5-inch[1]		6-inch[1]		7-inch[1]		8-inch[1]		10-inch[1]	
Liters per second	Gallons per minute	16-gage	14-gage	12-gage	14-gage	12-gage	14-gage	12-gage	14-gage	12-gage	14-gage	12-gage	14-gage	12-gage
2.54	40	0.150	0.155	0.169	0.048	0.052								
3.15	50	.218	.227	.246	.074	.080								
3.79	60	.300	.312	.339	.106	.113								
4.42	70	.393	.411	.444	.142	.151								
5.05	80	.558	.579	.628	.182	.193	0.074	0.079						
5.68	90	.677	.709	.768	.228	.242	.091	.096						
6.31	100	.810	.848	.920	.279	.296	.109	.115	0.052	0.054				
7.90	125	1.28	1.34	1.45	.425	.452	.172	.181	.079	.082				
9.50	150	1.76	1.83	1.99	.602	.640	.235	.249	.111	.116				
11.00	175	2.42	2.52	2.73	.807	.857	.323	.341	.148	.155	0.075	0.080		
12.62	200	3.04	3.17	3.44	1.04	1.10	.407	.429	.191	.200	.096	.100		
15.78	250	4.79	5.01	5.43	1.59	1.69	.643	.678	.292	.306	.152	.159	0.050	0.052
18.93	300	6.74	7.04	7.63	2.25	2.39	.903	.953	.414	.432	.215	.223	.070	.072
22.08	350	8.99	9.41	10.2	3.01	3.23	1.21	1.27	.555	.579	.287	.297	.095	.097
25.24	400	11.5	12.1	13.1	3.88	4.12	1.55	1.63	.714	.746	.369	.381	.120	.124
28.39	450	14.4	15.3	16.3	4.85	5.16	1.94	2.04	.894	.934	.458	.476	.150	.155
31.55	500	17.6	18.6	19.9	5.93	6.30	2.36	2.49	1.09	1.14	.559	.580	.183	.189
37.86	600				8.38	8.91	3.39	3.57	1.54	1.61	.801	.834	.263	.271
44.17	700				11.2	11.9	4.51	4.76	2.07	2.16	1.07	1.11	.352	.361
50.48	800				14.5	15.4	5.79	6.10	2.67	2.79	1.37	1.42	.450	.464
56.79	900						7.28	7.68	3.34	3.48	1.73	1.79	.573	.584
63.10	1000						8.90	9.38	4.08	4.26	2.11	2.18	.694	.712
75.72	1200						12.5	13.2	5.76	6.02	3.04	3.07	.977	1.00
88.34	1400								7.73	8.07	3.98	4.14	1.30	1.35
101.	1600								9.96	10.4	5.13	5.33	1.68	1.74
114.	1800										6.43	6.66	2.12	2.17
126.	2000										7.86	8.18	2.62	2.65
159.	2500										12.0	12.5	3.97	4.05
189.	3000												5.52	5.74

[1]Outside diameters.

*To convert meters loss per 100 meters multiply by 1.0.

Table 15. Friction head loss in semi-rigid plastic irrigation pipelines manufactured of PVC or asbestos compounds

(Standard Dimension Ratio - SDR = 21)[1]

Flow		Friction head loss in feet per hundred feet*						
Lit./Sec	GPM	1-inch 1.189 ID	1-1/4-inch 1.502 ID	1-1/2-inch 1.720 ID	2-inch 2.149 ID	2-1/2-inch 2.601 ID	3-inch 3.166 ID	3-1/2-inch 3.620 ID
.126	2	.15	.04	.02				
.252	4	.54	.17	.09	.03	.01		
.378	6	1.15	.37	.19	.06	.02		
.503	8	1.97	.63	.32	.11	.04	.01	
.631	10	2.98	.95	.49	.16	.06	.02	.01
.946	15	6.32	2.03	1.04	.35	.14	.05	.02
1.26	20	10.79	3.46	1.78	.60	.23	.09	.04
1.58	25	16.30	5.22	2.70	.91	.36	.13	.07
1.89	30	22.86	7.32	3.78	1.27	.50	.19	.10
2.21	35		9.75	5.03	1.70	.67	.25	.13
2.52	40		12.46	6.46	2.18	.86	.32	.17
2.84	45		15.51	8.02	2.71	1.07	.40	.21
3.15	50		18.87	9.75	3.30	1.30	.49	.25
3.47	55		22.48	11.64	3.94	1.54	.59	.30
3.79	60			13.64	4.62	1.81	.69	.36
4.10	65			15.85	5.36	2.10	.80	.41
4.42	70			18.19	6.14	2.42	.92	.47
4.73	75			20.65	6.99	2.75	1.06	.55
5.05	80			23.28	7.86	3.10	1.19	.62
5.36	85				8.81	3.47	1.33	.69
5.68	90				9.79	3.85	1.48	.77
5.99	95				10.82	4.25	1.64	.85
6.31	100				11.89	4.69	1.80	.93
6.94	110				14.21	5.59	2.14	1.11
7.57	120				16.69	6.56	2.52	1.31
8.20	130				19.35	7.63	2.92	1.53
8.83	140				22.21	8.73	3.36	1.75
9.46	150					9.94	3.82	1.99
10.10	160					11.20	4.29	2.24
10.73	170					12.51	4.80	2.50
11.36	180					13.90	5.35	2.79
11.99	190					15.39	5.92	3.08
12.62	200					16.91	6.50	3.38
13.88	220					20.19	7.77	4.04
15.14	240					23.73	9.12	4.76
16.41	260						10.57	5.51
17.67	280						12.11	6.32
18.93	300						13.78	7.18
20.19	320						15.52	8.10
21.45	340						17.37	9.07
22.72	360						19.27	10.08
23.98	380						21.33	11.13
25.24	400						23.45	12.22
26.50	420							13.40
27.76	440							14.59
29.03	460							15.86
30.29	480							17.15
31.55	500							18.50

Table based on Hazen-Williams equation - C_1 = 150

[1]To find friction head loss in PVC or ABS pipe having a standard dimension ratio other than 21, the values in the table should be multiplied by the appropriate conversion factor shown below:

SDR No.	Conversion Factor
13.5	1.35
17	1.13
21	1.00
26	.91
32.5	.84

*To convert to meters loss per 100 meters multiply by 1.0.

Table 15. Friction head loss in semi-rigid plastic irrigation pipelines manufactured of PVC or asbestos compounds (Cont)

(Standard Dimension Ratio - SDR = 21)

Flow		Friction head loss in feet per hundred feet*					
Lit./Sec	GPM	4-inch 4.072 ID	5-inch 5.033 ID	6-inch 5.993 ID	8-inch 7.805 ID	10-inch 9.728 ID	12-inch 11.538 ID
37.86	600	14.61	5.21	2.22	.61	.21	.09
41.01	650	16.94	6.04	2.58	.71	.24	.10
44.17	700	19.45	6.92	2.96	.81	.28	.12
47.32	750	22.08	7.87	3.36	.93	.32	.14
50.48	800		8.88	3.78	1.04	.36	.16
53.63	850		9.93	4.24	1.17	.40	.17
56.79	900		11.05	4.71	1.30	.44	.19
59.84	950		12.18	5.21	1.44	.49	.21
63.10	1000		13.40	5.73	1.58	.54	.23
66.25	1050		14.67	6.27	1.73	.59	.26
69.41	1100		16.00	6.83	1.88	.65	.28
72.56	1150		17.39	7.41	2.05	.70	.30
75.72	1200		18.80	8.02	2.21	.76	.33
78.87	1250		20.27	8.66	2.39	.82	.35
82.03	1300		21.78	9.32	2.57	.88	.37
85.18	1350			9.99	2.76	.95	.40
88.34	1400			10.66	2.95	1.01	.43
91.49	1450			11.40	3.16	1.08	.47
94.65	1500			12.13	3.35	1.15	.50
101.	1600			13.68	3.78	1.30	.56
107.	1700			15.29	4.23	1.45	.62
114.	1800			16.99	4.70	1.62	.70
120.	1900			18.81	5.20	1.79	.77
126.	2000			20.66	5.72	1.97	.84
133.	2100			22.61	6.26	2.15	.93
139.	2200			24.67	6.83	2.34	1.01
145.	2300				7.42	2.55	1.10
151.	2400				8.02	2.76	1.19
158.	2500				8.67	2.97	1.29
164.	2600	SDR No.	Factor		9.31	3.20	1.39
170.	2700	13.5	1.35		9.98	3.43	1.49
177.	2800	17	1.13		10.67	3.67	1.59
183.	2900	21	1.00		11.39	3.92	1.69
189.	3000	26	.91		12.10	4.17	1.81
197.	3100	32.5	.84		12.89	4.43	1.92
202.	3200				13.66	4.71	2.04
208.	3300				14.46	4.97	2.15
215.	3400				15.29	5.27	2.28
221.	3500				16.11	5.56	2.41
227.	3600				16.99	5.85	2.53
233.	3700				17.89	6.17	2.67
240.	3800				18.76	6.47	2.80
246.	3900				19.69	6.79	2.94
252	4000				20.67	7.11	3.08

*To convert to meters loss per 100 meters multiply by 1.0.

Table 15. Friction head loss in semi-rigid plastic irrigation pipelines manufactured of PVC or asbestos compounds (Cont)

(Standard Dimension Ratio - SDR 21)

Flow		Friction head loss in feet per hundred feet*					
Lit./Sec	GPM	4-inch 4.072 ID	5-inch 5.033 ID	6-inch 5.993 ID	8-inch 7.805 ID	10-inch 9.728 ID	12-inch 11.538 ID
.946	15	.01					
1.26	20	.02					
1.58	25	.04	.01				
1.89	30	.05	.02				
2.21	35	.07	.02	.01			
2.52	40	.09	.03	.01			
2.84	45	.12	.04	.01			
3.15	50	.14	.05	.02			
3.47	55	.17	.06	.02			
3.79	60	.20	.07	.03			
4.10	65	.23	.08	.03	.01		
4.42	70	.27	.09	.04	.01		
4.73	75	.31	.11	.04	.01		
5.05	80	.35	.12	.05	.01		
5.36	85	.39	.14	.05	.01		
5.68	90	.43	.15	.06	.01		
5.99	95	.48	.17	.07	.02		
6.31	100	.52	.19	.07	.02		
6.84	110	.63	.22	.09	.02		
7.57	120	.74	.26	.10	.03	.01	
8.20	130	.85	.30	.12	.03	.01	
8.83	140	.98	.35	.14	.04	.01	
9.46	150	1.11	.40	.16	.05	.01	
10.10	160	1.26	.44	.19	.05	.01	
10.73	170	1.41	.49	.21	.06	.02	
11.36	180	1.57	.55	.24	.07	.02	.01
11.99	190	1.73	.61	.26	.07	.02	.01
12.62	200	1.90	.67	.29	.08	.02	.01
13.88	220	2.28	.81	.34	.09	.03	.01
15.14	240	2.67	.95	.40	.10	.03	.01
16.41	260	3.10	1.10	.46	.12	.04	.02
17.67	280	3.56	1.26	.54	.14	.05	.02
18.93	300	4.04	1.43	.61	.17	.05	.02
20.19	320	4.56	1.62	.69	.19	.06	.03
21.45	340	5.10	1.82	.77	.21	.07	.03
22.72	360	5.67	2.02	.86	.24	.08	.03
23.98	380	6.26	2.22	.95	.26	.09	.04
25.24	400	6.90	2.45	1.04	.28	.10	.04
26.50	420	7.55	2.69	1.14	.31	.10	.05
27.76	440	8.23	2.92	1.25	.34	.11	.05
29.03	460	8.94	3.18	1.35	.37	.12	.06
30.29	480	9.67	3.44	1.46	.41	.14	.06
31.55	500	10.42	3.70	1.58	.43	.15	.06
34.70	550	12.44	4.42	1.89	.52	.18	.07
37.86	600	14.61	5.21	2.22	.61	.21	.09

SRD No.	Factor
13.5	1.35
17	1.13
21	1.00
26	.91
32.5	.84

*To convert to meters loss per 100 meters multiply by 1.0.

Table 16. Friction loss in feet per 100 feet in asbestos cement pressure pipe*

Flow		Nominal pipe diameter in inches				
Lit./sec	GPM	4	6	8	10	12
		I.D. = 3.95	I.D. = 5.85	I.D. = 7.85	I.D. = 10.00	I.D. = 12.00
6.31	100	0.677				
7.57	120	.954				
8.83	140	1.28				
10.10	160	1.65				
11.36	180	2.06				
12.62	200	2.53	0.372			
13.88	220	3.03	.447			
15.14	240	3.56	.525			
16.41	260	4.16	.611			
17.67	280	4.77	.705			
18.93	300	5.44	.803			
20.19	320	6.16	.910			
21.45	340	6.91	1.02			
22.72	360	7.70	1.14			
23.48	380	8.54	1.26			
25.24	400	9.40	1.39	0.324		
26.50	420	10.3	1.52	.355		
27.76	440	11.3	1.66	.389		
29.03	460	12.3	1.81	.423		
30.29	480	13.3	1.96	.458		
31.55	500	14.4	2.12	.495		
34.70	550	17.2	2.55	.594		
37.86	600	20.3	2.99	.701	0.214	
41.01	650	23.7	3.49	.818	.249	
44.17	700	27.3	4.02	.935	.287	
47.32	750	31.1	4.57	1.07	.328	
50.48	800		5.18	1.21	.370	0.152
53.63	850		5.81	1.36	.415	.170
56.79	900		6.46	1.51	.464	.190
59.94	950		7.17	1.68	.511	.210
63.10	1000		7.91	1.85	.564	.232
69.49	1100		9.45	2.21	.675	.278
75.72	1200		11.2	2.62	.800	.328
82.03	1300		13.0	3.04	.932	.384
88.34	1400		15.0	3.50	1.07	.438
94.65	1500		17.1	3.99	1.22	.502
101.0	1600		19.3	4.52	1.38	.566
107.3	1700			5.06	1.55	.637
114.0	1800			5.67	1.73	.710
120.0	1900			6.26	1.91	.787
126.0	2000			6.90	2.11	.864
139.0	2200			8.27	2.53	1.04
151.0	2400			9.75	2.98	1.23
164.0	2600			11.4	3.47	1.43
177.0	2800			13.1	4.00	1.64
189.0	3000			14.9	4.56	1.87

From Scobey's formula

$$H_f = K_s \frac{V^{1.9}}{D^{1.1}}$$

where H_f = head loss in 1000 feet of pipe

K_s = roughness coefficient = 0.32

V = velocity in feet per second

D = inside pipe diameter in feet.

* To convert to meters loss per 100 meters multiply by 1.0.

FEEL AND APPEARANCE METHOD OF DETERMINING HOW MUCH WATER TO APPLY:

(From Soil Conservation Service, USDA)

Description of Method:

The best way of determining how much water to apply is to measure the amount of moisture in the soil and the amount that the soil will hold at field capacity. However this is time consuming and requires special equipment that is not commonly owned by irrigators.

A common method in use is the feel and appearance method where the amount of moisture present is estimated. When the field capacity of the soil is known, the amount of moisture needed is then easy to calculate.

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%. The photographs and descriptions of moisture conditions can be used to aid in the determination of moisture present in the soil and amount needed to reach field capacity.

Example:

Assume a silt loam soil is to be irrigated. Samples are taken at the 6", 18" and 36" depths. Select page showing medium texture soils and assume moisture conditions closely resemble the first photograph for the 6" depth, between the 2nd and 3rd for the 18" depth and between the 3rd and 4th for the 36" depth. Then percent available would be 25, 50 and 75% respectively.

From moisture deficiency table, the top foot would need 1.5", the second foot would need 1.0" and the third and fourth foot 0.5" per foot, or a total of 3.5" for the four foot zone.

Obtaining samples:

For row crops, measurements should be made in the row or near the plants. In sprinkler irrigation, the measuring stations should be between the sprinkler heads and 10 to 15 feet away from the lateral.

Measurements should be made in that part of the soil from which plant roots extract their moisture and according to the moisture-extraction pattern of the particular crop. One measurement should be made in the upper quarter of the root zone and one or two more measurements, at lower levels. If the maximum moisture-extraction depth for a given crop is 48 inches, for example, measurements probably should be made at about 6, 18, and 36 inches. To predict when to irrigate during the early stages of root development, the 6-inch measurement is all that is needed for most crops. As the root system reaches maturity, measurements from all three depths are needed for a clear picture of the moisture level throughout the moisture-extraction zone.

Table 17. Guide for judging how much moisture is available for crops

Available soil moisture remaining	Feel or appearance of soil and moisture deficiency			
	Loamy Sand	Sandy Loam	Loam and Silt Loam	Clay Loam or Silty Clay Loam
0 to 25 percent	Dry, loose, single grained, flows through fingers.	Dry, loose, flows through fingers.	Powdery dry, sometimes slightly crusted but easily broken down into powdery condition.	Hard, baked, cracked, sometimes has loose crumbs on surface.
Moisture deficiency* (inches per foot)	.90 to .70	1.3 to 1.0	2.0 to 1.5	2.2 to 1.65
25 to 50 percent	Appears to be dry, will not form a ball with pressure.[1]	Appears to be dry, will not form a ball.[1]	Somewhat crumbly but holds together from pressure.	Somewhat pliable, will ball under pressure.[1]
Inches/ft.	.70 to .45	1.0 to .65	1.5 to 1.0	1.65 to 1.10
50 to 75 percent	Appears to be dry, will not form a ball with pressure.	Tends to ball under pressure but seldom holds together.	Forms a ball somewhat plastic, will sometimes slick slightly with pressure.	Forms a ball, ribbons out between thumb and forefinger.
Inches/ft.	.45 to .20	.65 to .30	1.0 to 0.5	1.10 to .55
75 percent to field capacity (100 percent).	Tends to stick together slightly, sometimes forms a very weak ball under pressure.	Forms weak ball, breaks easily, will not slick.	Forms a ball, is very pliable, slicks readily if relatively high in clay.	Easily ribbons out between fingers, has slick feeling.
Inches/ft.	.20 to .00	.30 to .00	0.5 to .00	.55 to .00
At field capacity (100 percent)	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.
	.00	.00	.00	.00

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

*To convert moisture deficiency from inches/foot to mm/cm multiply by . 833.

Table 18. Values of the climatic coefficient, k_t, 1/ for various mean air temperature, t.

t °F	k_t	t °F	k_t	t °F	k_t
36	.31	61	.74	86	1.17
37	.33	62	.76	87	1.19
38	.34	63	.78	88	1.21
39	.36	64	.79	89	1.23
40	.38	65	.81	90	1.24
41	.40	66	.83	91	1.26
42	.41	67	.85	92	1.28
43	.43	68	.86	93	1.30
44	.45	69	.88	94	1.31
45	.46	70	.90	95	1.33
46	.48	71	.91	96	1.35
47	.50	72	.93	97	1.36
48	.52	73	.95	98	1.38
49	.53	74	.97	99	1.40
50	.55	75	.98	100	1.42
51	.57	76	1.00		
52	.59	77	1.02		
53	.60	78	1.04		
54	.62	79	1.05		
55	.64	80	1.07		
56	.66	81	1.09		
57	.67	82	1.11		
58	.69	83	1.12		
59	.71	84	1.14		
60	.72	85	1.16		

1/ Values of (k_t) are based on the formula, $k_t = .0173\ t - .314$

for mean temperatures less than 36°, use $k_t = .300$.

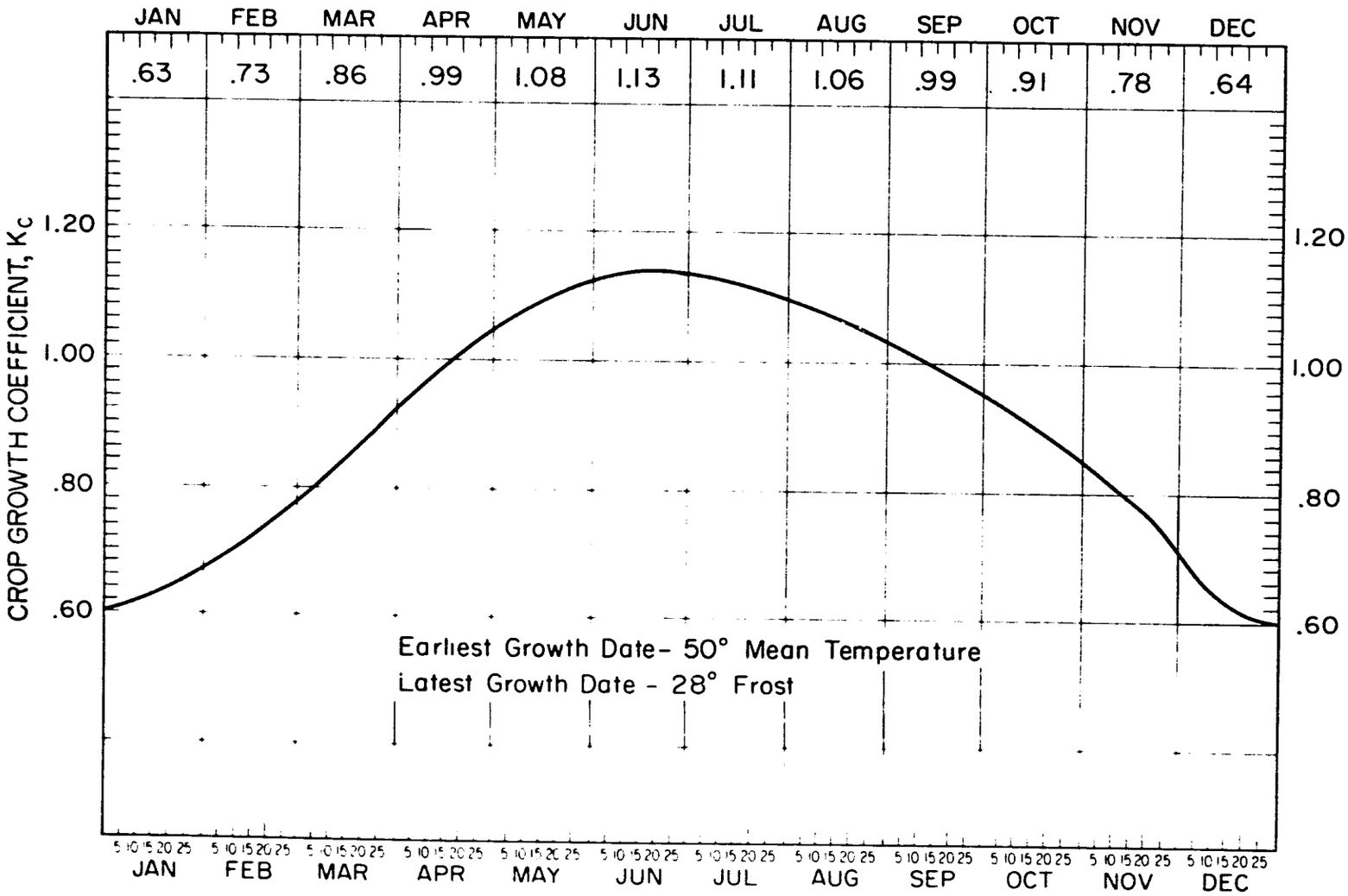


Figure 33. Crop growing coefficient curve for alfalfa.

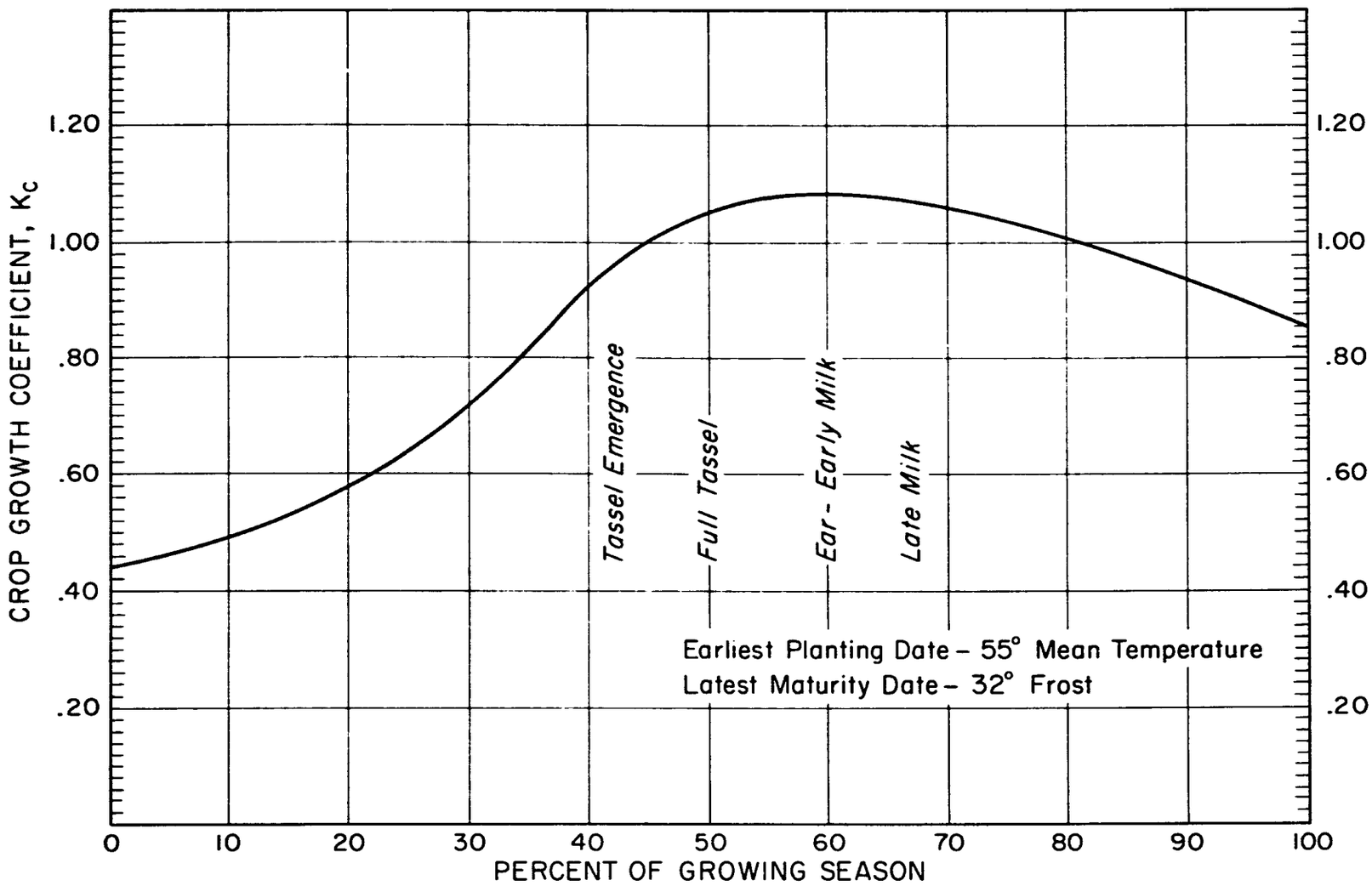


Figure 34. Crop growing coefficient curve for grain.

SOIL CONSERVATION SERVICE

National Engineering Standard
and
Specifications Guide (Feb. 1967)
for
IRRIGATION PIPELINES
(High Pressure Underground Plastic)

Definition

An irrigation pipeline is a pipe or other closed conduit installed in an irrigation system.

Scope

This standard applies to underground pipelines constructed of thermoplastic pipe that are closed to the atmosphere, and are subject to internal pressures up to 315 pounds per square inch.

This standard covers (1) the design criteria for high pressure irrigation pipelines, (2) the minimum installation requirements for plastic pipelines one to twelve inches in diameter and (3) the specification for the thermoplastic pipe to be used.

Conditions Where Practice Applies

All pipelines shall be planned and located to serve as integral parts of an irrigation water distribution or conveyance system that has been designed to facilitate the conservation use and management of the soil and water resources on a farm or a group of farms.

Water supplies and rates of irrigation delivery for the area served by the pipeline shall be sufficient to make irrigation practical for the crops to be grown and the irrigation water application method to be used.

Plastic pipelines installed under this standard shall be installed only in suitable soils where the backfill and bedding requirements can be fully met.

Design Criteria

Working Pressure

The pipeline shall be designed in such a manner that the maximum working pressure in the line does not exceed the water pressure rating shown in Table 19 for the type and grade of compound used in manufacture of the

pipe and for the selected standard dimension ratio. Pipe having a water pressure rating less than 50 pounds per square inch shall not be used.

Solvent Welded Joints

The maximum standard dimension ratio for solvent welded thermoplastic pipe shall be SDR 26 for 2-½" diameters and smaller, and for larger sizes the minimum wall thickness shall be 0.098 inch.

Capacity

The design capacity of the pipeline shall be based on whichever of the following criteria is the greater:

a. The capacity shall be sufficient to deliver the volume of water required to meet the peak-period consumptive use of the crop or crops to be irrigated.

b. The capacity shall be sufficient to provide an adequate irrigation stream for all methods of irrigation planned.

Friction Losses

For design purposes, friction head losses shall be no less than those computed by the Hazen-Williams equation using a roughness coefficient, C_1, equal to 150.

Outlets

Such appurtenances as are required to deliver water from the pipeline to an individual sprinkler or to a lateral line of sprinklers or surface pipe located on the ground surface shall be known as outlets. Outlets shall have a capacity adequate to deliver the design flow to (1) an individual sprinkler or (2) a surface lateral line of sprinklers or surface pipe at the design operating pressure of the sprinkler or lateral line or surface pipe as the case may be.

Check Valves, Pressure Relief, Vacuum Release and Air Release Devices

A check valve shall be installed between the pump discharge and the pipe line where detrimental backflow may occur.

A pressure relief valve shall be installed between the pump discharge and the pipeline when excessive pressures can be developed by operating with all valves closed. Also in closed systems where the line is protected

from reversal of flow by a check valve and excessive surge pressures could be developed, a surge chamber or a pressure relief valve shall be installed.

Pressure relief valves or surge chambers shall be installed at the end of the pipe line when needed to relieve surge at the end of the line. Pressure relief valves shall be no smaller than ¼ inch normal size for each diameter inch of the pipeline, and shall be set at a maximum of 5 psi above the pressure rating of the pipe.

Air release and/or vacuum release valves shall be placed at all summits in the pipeline and at the end of the line when needed to provide a positive means for air entrance or air escape.

Air release and vacuum release valve outlets of at least one-half inch nominal diameter shall be used in lines of 4 inches or less in diameter, at least one inch outlets shall be used in lines of 5 to 8 inches in diameter, and no smaller than two inch outlets shall be used in lines of 10 to 12 inches in diameter.

Draining and Flushing Requirements

Provisions shall be made for draining the pipeline completely where (1) a hazard is imposed by freezing temperatures, (2) drainage is recommended by the manufacturer of the pipe or (3) drainage of the line is specified for the job for any reason. Where provisions for drainage are required, drainage outlets shall be located at all low places in the line and air inlets provided at summits to prevent the development of negative pressures. These outlets may drain into dry wells or to points of lower elevation. If drainage cannot be thus provided by gravity, provisions shall be made to empty the line by pumping.

Where provisions are needed to flush the line free of sediment a suitable valve shall be installed at the distal end of the pipeline.

SOIL CONSERVATION SERVICE

Specification Guide
for
IRRIGATION PIPELINES
(High Pressure Underground Plastic)

Joints and Connections

All joints and connections shall be constructed to withstand the design maximum working pressure for the pipeline without leakage and shall leave the inside of the line free of any obstruction that may tend to reduce its capacity below design requirements.

All fittings, such as couplings, reducers, bends, tees and crossings shall be made of material that is recommended for use with pipe and shall be installed in accordance with the recommendations of the pipe manufacturer.

Where fittings made of steel or other metals subject to corrosion are used in the line, they shall be adequately protected by wrapping with plastic tape or coating with high quality corrosion preventatives. Where plastic tape is used all surfaces to be wrapped shall be thoroughly cleaned and then coated with a primer compatible with the tape prior to wrapping.

Installation Requirements

The pipe shall be allowed to come to within a few degrees of the temperature that it will have after complete covering prior to any backfilling beyond shading. The pipeline shall be installed at sufficient depth below the ground surface to provide protection from hazards imposed by traffic crossing, farming operations, freezing temperatures, or soil cracking. The minimum depth of cover shall be 18 inches for pipe sizes 1 inch through 2½ inches in diameter. For pipe sizes 3 inch , 3½ inch, and 4 inch the minimum depth of cover shall be 24 inches. For pipe sizes of 5 inches or larger the minimum depth of cover shall be 30 inches. At low places on the ground surface, extra fill may be placed over the pipeline to provide the minimum depth of cover. In such cases the top width of the fill shall be no less than 10 feet and the side slopes no steeper than 6 horizontal to 1 vertical.

Where rock, hardpan, boulders or any other material which might damage the pipe are encountered, the trench shall be undercut a minimum of 4 inches below final grade. The material used to establish final grade shall be sand or fine graded stable soil.

Testing

The pipeline shall be thoroughly and completely tested for pressure strength and leakage before backfill operations are undertaken. The line shall be filled with water, taking care to bleed all entrapped air in the process. The pressure shall be slowly built up to the

maximum design working pressure. The line shall be inspected in its entirety while the maximum working pressure is maintained. Where leaks are discovered they shall be promptly repaired and the line shall be re-tested. In some cases, it may be necessary to partially backfill the line before testing in order to hold the line in place. Where such is the case, the partial backfill shall be undertaken in accordance with the provisions specified under Backfilling covering only the body of the pipe sections and leaving all joints and connections uncovered for inspection purposes.

It shall be demonstrated by testing that the pipeline will function properly at design capacity. At or below design capacity, there shall be no objectionable surge or water hammer. To be objectionable there shall be either (1) continuing unsteady delivery of water, (2) damage to the pipeline, or (3) detrimental overflow from control valves.

Backfilling

The pipe shall be uniformly and continuously supported. Blocking or mounding shall not be used to bring the pipe to final grade.

The initial backfill shall be of selected material free from rocks, stones, or clods greater than approximately ½ inch in diameter. The initial fill shall be compacted firmly around and above the pipe to achieve a soil density equal to or exceeding the natural density of the undisturbed sidewalls of the trench. Care shall be taken to avoid deformation or displacement of the pipe during this phase of the operations.

When water packing is used the pipeline shall be filled with water. The initial backfill, before wetting shall be of sufficient depth to insure complete coverage of the pipe after consolidation has taken place. Water packing is accomplished by adding water in such quantity as to thoroughly saturate the initial backfill without inundation. After saturation, the valves shall be closed and the pipeline shall remain full until final backfill is made. The wetted fill shall be allowed to dry until firm before final backfill is begun.

The remainder of the backfill shall be placed and spread in approximately uniform layers in such a manner as to completely fill the trench so that there will be no unfilled spaces in the backfill. Final backfill material shall be free of rocks or boulders greater than 3 inches in diameter and shall be added and compacted in a manner that will leave the fill at ground level after settlement has taken place. Rolling equipment shall not be used until a minimum of 18 inches of backfill material has been placed over the top of the pipe.

All special requirements of the manufacturer shall be strictly observed.

Construction Materials

Quality of Plastic Pipe

The compound used in manufacturing the pipe shall meet the requirements of one of the following materials:

a. Polyvinyl Chloride (PVC) as specified in ASTM D-1784-65T. Type 1 Grade 1 - Type I, Grade 2 - Type II, Grade 1.

b. Acrylonitrile-Butadiene-Styrene (ABS) as specified in ASTM D-1788-62T. Type I, Grade 2-Type II, Grade 1.

c. Polyethylene (PE) as specified in ASTMD-1248-63T. Type II, Grade 3 - Type III, Grade 2 - Type III, Grade 3.

The pipe shall be homogeneous throughout and free from visible cracks, holes, foreign inclusion or other defects. The pipe shall be as uniform as commercially practicable in color, opacity, density and other physical properties.

Pipe Requirements

The wall thickness shall be as determined by the standard dimension ratio (SDR) for a given allowable working pressure applicable to the type and grade of compound used in the manufacture of the pipe, as given in Table I.

The pipe shall meet (A) for IPS [1] - sized pipe all the applicable dimensional and quality requirements given in the Commercial Standards and/or ASTM specification listed in Table 2, or (b) for PIP [2] - sized pipe the dimensional requirements given in Tables 3 and 4, and the requirements except those concerned with outside diameters and wall thickness of the applicable Commercial Standards and/or ASTM specification listed in Table 2.

Tables 1 and 2 shall be considered revised to delete or to include additional plastic pipe materials as they are deleted or added to the applicable Commercial Standards and/or ASTM specifications listed in Table 2.

Fitting Requirements

Fittings for IPS-sized pipe shall meet all the dimensional and quality requirements given in the following applicable ASTM specifications:

ASTM D2464 - PVC Fittings Threaded, Schedule 80
ASTM D2465 - ABS Fittings Threaded, Schedule 80
ASTM D2466 - PVC Fittings Socket, Schedule 40
ASTM D2467 - PVC Fittings Socket, Schedule 80
ASTM D2468 - ABS Fittings Socket, Schedule 40
ASTM D2469 - ABS Fittings Socket, Schedule 80

Marking

The pipe shall be adequately marked at intervals of not more than 5 feet. Markings shall include the following:

a. The nominal pipe size and the size system that applies (IPS or PIP); e.g., 4-IPS or 4-PIP.

1/ Outside diameter same as "Iron Pipe Sizes" (IPS)

2/ Plastic Irrigation Pipe

Table 19. Water pressure ratings in p.s.i. for various types, grades, and standard dimension ratios of non-threaded plastic pipes

SDR 1/	PVC Materials				ABS Materials			PE MATERIAL		
	PVC 1120 PVC 1220 PVC 2120	PVC 2116	PVC 2112	PVC 2110	ABS 1316	ABS 1210	ABS 1208	PE 3206 PE 3306	PE 2306	PE 2305
7										125
9								125	125	100
11.5								100	100	80
13.5	315	250	200	160	250	160	125	80	80	63
17	250	200	160	125	200	125	100	63	63	50
21	200	160	125	100	160	100	80	50	50	
26	160	125	100	80	125	80	63			
32.5	125	100	80	63	100	63	50			
41	100	80	63	50	80	50				
51	80	63	50		63					

1/ SDR = Standard dimension ratio

SDR = Average outside diameter (inches) for PVC and ABS pipe
Minimum wall thickness (inches)

SDR = Average inside diameter (inches) for PE pipe
Minimum wall thickness (inches)

SDR 32.5 to be used only for 3" diameter or larger
SDR 41 to be used only for 3-½" diameters or larger
SDR 51 to be used only for 5" diameter or larger

Table 19 (Cont.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
					IPS - sized pipe	
Compound	Type	Grade	Hydrostatic Design Stress	Designation	Commercial Standard	ASTM No.
PVC	I	1	2000 p.s.i.	PVC 1120	256	D-2241
PVC	I	2	2000 p.s.i.	PVC 1220	256	D-2241
PVC	II	1	1000 p.s.i.	PVC 2110	256	D-2241
PVC	II	1	1250 p.s.i.	PVC 2112	256	D-2241
PVC	II	1	1600 p.s. i.	PVC 2116	256	D-2241
PVC	II	1	2000 p.s.i.	PVC 2120	256	D-2241
ABS	I	2	1000 p.s.i.	ABS 1210	254	D-2282
ABS	I	3	1600 p.s.i.	ABS 1316	254	D-2282
ABS	I	2	800 p.s.i.	ABS 1208	254	D-2282
ABS	II	1	1250 p.s.i.	ABS 2112	254	D-2282
PE	II	3	500 p.s.i.	PE 2305	255	D-2239
PE	II	3	630 p.s.i.	PE 2306	255	D-2239
PE	III	2	630 p.s.i.	PE 3206	255	D-2239
PE	III	3	630 p.s.i.	PE 3306	255	D-2239

Table 20. Wall thickness of Plastic Irrigation Pipe (PIP)

PIP Size inch	Wall thickness[a] SDR 51 Minimum	SDR 51 Tolerance	SDR41 Minimum	SDR41 Tolerance	SDR 32.5 Minimum	SDR 32.5 Tolerance	SDR26 Minimum	SDR26 Tolerance
	inch	inch	inch	inch	inch	inch	inch	inch
4	-	-	0.101	+0.020	0.127	+0.020	0.159	+0.020
6	0.120	+0.020	0.150	+0.020	0.189	+0.023	0.236	+0.028
8	0.160	+0.020	0.199	+0.024	0.251	+0.031	0.314	+0.038
10	0.200	+0.024	0.249	+0.030	0.314	+0.038	0.392	+0.047
12	0.240	+0.029	0.299	+0.036	0.377	+0.045	0.471	+0.056

PIP Size inch	Wall Thickness[a] SDR21 Minimum	SDR21 Tolerance	SDR17 Minimum	SDR17 Tolerance	SDR13.5 Minimum	SDR13.5 Tolerance
	inch	inch	inch	inch	inch	inch
4	0.197	+0.024	0.243	+0.029	0.306	+0.037
6	0.292	+0.035	0.361	+0.043	0.455	+0.054
8	0.389	+0.047	0.480	+0.058	0.604	+0.072
10	0.486	+0.058	0.600	+0.072	0.756	+0.091
12	0.583	+0.070	0.720	+0.086	0.907	+0.109

a. The minimum is the least wall thickness of the pipe at any cross section. All tolerances are on the plus side of the minimum requirement.

Table 21. Outside diameters of Plastic Irrigation Pipe (PIP)

For ABS and PVC Pipe

PIP Size inch	Outside Diameter inch	Tolerance: For average measurements inch	Tolerance: For maximum and minimum: SDR 51, SDR 41, SDR 32.5, SDR 26, SDR 21 inch	Tolerance: For maximum and minimum: SDR 17 SDR 13.5 inch
4	4.130	+0.009	±0.050	±0.015
6	6.140	±0.011	±0.050	±0.030
8	8.160	±0.015	±0.070	±0.042
10	10.200	±0.015	±0.075	±0.050
12	12.240	±0.015	±0.075	±0.060

APPENDIX 1

Requirements in addition to those in CS-256 or ASTM D-2241 for IPS-OD pipe.

Wall thicknesses and tolerances for SDR51 PVC plastic pipe

Nominal Pipe Size inch	SDR51 Minimum Wall inch	SDR51 Tolerance inch
5	0.109	+0.020
6	0.130	+0.020
8	0.169	+0.020
10	0.211	+0.025
12	0.250	+0.030

Sustained pressure test conditions for water at 23C (73F) for SDR 51 PVC plastic pipe

Standard Dimension Ratio	Pressure (1) required for test: PVC 1120, PVC 1220, PVC 2120 psi	PVC 2116 psi	PVC 2112 psi	PVC 2110 psi
SDR 51	170	135	115	90

1. The fiber stresses used to derive these test pressures are as follows:

PVC 1120 - 4200 psi	PVC 2116 - 3360 psi
PVC 1220 - 4200 psi	PVC 2112 - 2800 psi
PVC 2120 - 4200 psi	PVC 2110 - 2300 psi

Some minor adjustments have been made to keep the test pressures uniform to simplify testing.

Burst pressure requirements for water at 23C (73F) for SDR 51 PVC plastic pipe

Standard Dimension Ratio	Minimum burst pressures (1): PVC 1120, PVC 1220, PVC 2120 psi	PVC 2116, PVC 2112, PVC 2110 psi
SDR 51	260	200

1. The fiber stresses used to derive these test pressures are as follows:

PVC 1120 - 6400 psi	PVC 2116 - 5000 psi
PVC 1220 - 6400 psi	PVC 2112 - 5000 psi
PVC 2120 - 6400 psi	PVC 2110 - 5000 psi

Some minor adjustments have been made to keep the test pressures uniform to simplify testing.

b. The type of plastic pipe material in accordance with the designation code; e.g., PVC 1120.

c. The pressure rating in p.s.i. for water at 73.4° F.;e.g., 200 p.s.i.

d. (A) The Commercial Standard or ASTM specification designation with which the pipe complies for IPS-sized pipe, or (B) the designation PIP for pipe in this size system e.g. CS 256 or PIP.

e. The manufacturer's name (or trademark) and code.

Basis of Acceptance

The acceptability of the pipeline shall be determined by inspections to check compliance with all the provisions of this standard with respect to (1) the design of the line, (2) the pipe and appurtenances used, and (3) the minimum installation requirements.

Certification and Guarantee

All material shall conform to these minimum requirements and to the tests prescribed in the applicable Commercial Standard or ASTM Specification. The pipe shall be certified by a qualified testing laboratory (Note 1) for compliance with this National Engineering Standard and Specifications Guide.

The Installing Contractor shall certify that his installation complies with the requirements of this specification. He shall furnish a written guarantee designed to protect the owner against defective workmanship and materials over a period of not less than two years.

Note 1. Pipe that bears the seal of approval of the National Sanitation Foundation may be considered acceptable for this certification.

Attachment No.1

ASAE RECOMMENDATION:

Minimum Requirements for the Design, Installation and Performance of Sprinkler Irrigation Equipment

This recommendation was sponsored by the Subcommittee on Sprinkler Irrigation of the Committee on Irrigation, Soil and Water Division, American Society of Agricultural Engineers, and received the official endorsement of the Sprinkler Irrigation Association at its annual convention at Biloxi, Miss., in November, 1952. It was approved February, 1953, as an official ASAE Recommendation.

THESE minimum requirements pertain to the design, installation, and performance of sprinkler irrigation equipment, and include dealer-purchaser responsibilities. The design and performance requirements are concerned particularly with those factors that are directly related to land, crops, and farm operations. The dealer-purchaser responsibilities recognize successful operation of a sprinkler system as depending on both buyer and seller.

PART I. DESIGN AND PERFORMANCE

1 Application Rate. A portable sprinkler irrigation system, when properly designed and operated, shall meet the following conditions with respect to water application:

(a) Apply water at a rate which does not cause runoff during the normal operating period nor cause water to stand on the surface of the ground after the sprinkler line is shut off.

(b) Determination of the proper rate of application *shall be the responsibility of the person designing the system.* Values for bare ground infiltration rates for different types of local soils may be obtained from responsible agricultural technicians. In the absence of such technical advice, the designer may estimate the proper application rate on the basis of past experience with similar soil types.

2 System Capacity.

(a) For regularly irrigated areas, the system shall have the capacity to meet the peak moisture demands of each and all crops irrigated within the area for which it is designed. Sufficient time must be allowed for moving laterals and for permitting cultural practices on the land. The capacity must also allow for reasonable water losses during application periods with the system operating in accord with design conditions.

(b) For supplemental irrigation and/or special uses, the system shall have the capacity to apply stated amount of water to the design area in a specified net operating period.

3 Depth of Water Application. In the design of the system, total depth of application (equivalent rainfall) per irrigation shall be governed by the capacity of the soil for moisture storage and the depth of the principal root zone of the crop irrigated. Information on both of these factors may be obtained from agricultural technicians or may be estimated by the designer on the basis of his past experience with similar soil types and crops.

4 Uniformity of Water Application. Since uniformity of water application is affected by both pressure in the line and spacing of sprinklers, recommendations for desirable operating pressures and spacings for different types of sprinklers and nozzle sizes shall be obtained from the sprinkler manufacturer.

Differences in pressures at the sprinklers shall be kept to a minimum to assure reasonably uniform distribution of water over the entire design area. A common rule, *which should be adhered to as closely as practicable,* is to limit pressure differences along a sprinkler lateral to 20 per cent of the higher pressure.

Excessive pressure differences in the main or supply line result in widely varying pressures at the head of the laterals. In many instances these excessive variations cannot be controlled by pipe size alone. Then the only practical alternative is to design for adequate pressure at the lateral take-off where pressure in the main will be lowest, and instruct the operator in regulating pressures into the other laterals by adjusting the take-off valve openings.

5 Crop Damage. Water shall be applied in a manner which will not cause direct physical damage to plants or fruit.

PART II. DEALER-PURCHASER RESPONSIBILITIES

A. Dealer Responsibility

1 Proper Design. When the system is planned by a dealer, or his representative, the dealer shall assume full responsibility for the proper design of the system he proposes to furnish. Design requirements to fit the system to conditions of soil, topography, water supply and crop enterprise shall be ascertained by the dealer either directly or by obtaining such information from recognized reliable sources.

When design requirements are furnished in writing by the purchaser, the dealer's responsibility shall be limited to the design of the system to meet the stated conditions.

When plans and specifications are furnished in writing by the purchaser, the dealer's responsibility shall be limited to supplying equipment which will satisfy the requirements of the specifications furnished.

When the purchaser buys the system piecemeal, he absolves all dealers of responsibility for the performance of the system as a unit.

2 Proper Installation. The dealer or his representative shall assume full responsibility for the proper installation of the system.

Pumps and power units shall be set on a firm base and care shall be taken to keep the pump and the motor or engine in proper alignment.

Wiring and starting equipment for electrically operated plants shall comply with approved standards. Electric motors shall be provided with overload and low-voltage protection.

Internal-combustion engines shall be provided with protective devices. Thermostats shall be supplied that stop the engine when water or oil temperatures exceed the safety point. Where conditions are such that a failure of the water supply might result in the pump losing its prime, the pumping plant shall be protected by a device that stops the engine. These devices may be dispensed with where conditions are such that there is little probability of water supply failure, or when the pumping plant is constantly attended.

3 Operating Instructions. The dealer or dealers furnishing equipment required for a complete sprinkler system shall furnish to the purchaser, in writing, such instructions, performance charts and layout drawings as are required to insure proper operation, in accord with design conditions and normal expected life for the type of equipment furnished.

4 Performance Warranty. When a dealer or associated group of dealers assumes responsibility for the design and installation of a sprinkler irrigation system, a warranty shall be furnished, stating specially the performance expected for water-application rate, capacity, rate of coverage for a specific design area serving specific crops and crop acreages as

stated by the purchaser and mutually understood to be the basis of design.

Warranty shall be based on trial of the system during operation under the range of operating conditions imposed on the system. The warranty shall not be expected to cover any conditions encountered which were beyond reasonable control of the dealer either in design or installation. Values used for infiltration rate, peak-use rate of moisture by crops, or capacity of soils to retain water for plants cannot be expected to be accurate for every local condition of soil. Evidence that the dealer has made reasonable efforts to obtain values from reliable sources shall be sufficient reason to absolve him from responsibility if such values do not represent local conditions.

When a dealer or dealers assume responsibility for the installation of a system in accord with specifications supplied by the purchaser, a warranty shall be furnished, stating the performance expected as to friction loss in the system, pump and engine motor characteristics, and other pertinent data pertaining to the specifications.

5 *Equipment Warranty.* The dealer or dealers assuming responsibility for the installation of the system shall furnish warranties covering the quality of material and workmanship of each piece of equipment furnished in accord with the original manufacturer's guarantee, and shall provide for replacement of defective parts shown to have failed because of poor quality materials or poor workmanship.

6 *Maintenance and Repair Service.* Dealers selling sprinkler irrigation systems in a territory shall maintain an inventory of replaceable parts and required equipment repair service. The extent of this available service shall be such that users in the territory will be assured of reasonable service which will avoid crop loss due to shutdown of a system for replacements or repairs

B. Purchaser Responsibility

1 *Operations in Accord with Instructions.* The purchaser and user of a sprinkler irrigation system shall assume responsibility for failure of the system to perform properly if, after receiving all data furnished by the dealer, he fails to operate the system in accord with all conditions assumed in the design of the system. To obtain the full life of all equipment the user shall observe the stated limits of operating conditions set forth by the manufacturer.

2 *Care and Maintenance Recommendations.* The purchaser shall follow the dealer's recommendations for care and maintenance of the equipment. This applies to periods of use as well as non-use of the equipment.

PART III. DEFINITIONS

Design Area. The specific land area which the supplier or designer and the purchaser mutually understand is to be irrigated by the sprinkler system.

Sprinkler Irrigation System. This includes all equipment required to apply water to the design area, from the source of water supplying the system to the revolving sprinkler, nozzles, or perforated pipe.

If water is already available to the design area, the system includes only the equipment required to develop the necessary pressure and apply the water to the area.

If both water and pressure are available, as in the case of an existing pressure line, the system includes only the equipment required to take water under pressure from the supply line and apply it to the design area.

Sprinkler Lateral. A line of portable pipe or tubing with sprinklers, nozzles, or perforations along the line. A lateral may be one of several operated from a common main supply line, or it may be a single unit supplied directly from the water source.

Application Rate. The equivalent rainfall rate expressed in inches of water depth per hour (acre-inches per acre per hour). For systems with rotating sprinklers, the rate is computed on the basis of the spacing of lateral settings, the spacing of the sprinklers along the lateral, and the average discharge of the sprinklers. For perforated pipe systems, the application rate is computed from lateral spacings, length of lateral, and average flow into the lateral.

Infiltration Rate. The rate at which soil will take in water during the irrigation period, expressed in inches of water depth per hour (acre-inches per acre per hour).

Peak Moisture Demand. Peak moisture demand of any crop is considered to be the maximum that occurs during periods of maximum temperature and crop growth. This peak demand for moisture on the part of a crop results from transpiration by the plants, and direct evaporation from the soil.

Adopted and published by THE AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS
130 Main Street, St. Joseph, Michigan

MINIMUM STANDARDS FOR IRRIGATION EQUIPMENT

Approved January, 1957; revised as Tentative Standard March 1959, adopted as ASAE Standard, 1962

Introduction

These standards have been formulated to afford reasonable protection and to provide a margin for deterioration in service so as to give a reasonably long, safe period of usefulness to the users of irrigation systems.

The standards will serve as a reference for minimum requirements by irrigation equipment manufacturers, engineers, suppliers, and others concerned with irrigation systems. The standards may also serve as a guide to state and other authorities in the drafting of regulations and it may be adopted by them in whole or in part.

By reference to these standards, or material specifications, the American Society of Agricultural Engineers does not undertake to insure anyone utilizing the standards or specifications against liability for infringement of letters patent or assume such liability, and such reference should not be construed as a recommendation of any patented proprietory application that may be involved.

The interests of manufacturers have also been recognized by taking into consideration advancements in design and material and the evidence of experience. Specific sanction is given for the use of materials and processes where their safety characteristics have been clearly demonstrated. Progress in the art has been anticipated by allowing the use of new materials and construction, having safety characteristics equal or superior to those specified. It is important, however, that at least the minimum requirements set up by this standard be maintained.

The technical specifications were agreed upon by manufacturer representatives at a meeting with the Technical Committee of the Sprinkler Irrigation Association. They were subsequently reviewed, revised and approved by the ASAE-SIA Liaison Committee and the ASAE Sprinkler Irrigation Research Committee.

The section which has been prepared and included in this edition of the standard is as follows:

SECTION I. IRRIGATION TUBING*

Part 1. Class 150—Hand Move Aluminum Irrigation Tubing

Appendix A—Table I, Allowable Working Stresses for Aluminum Alloys

SECTION I. IRRIGATION TUBING

101. *Scope:*

Section I of this standard prescribes minimum requirements for design, manufacture, and test of irrigation tubing.

102. *Classification:*

Irrigation tubing shall be understood to include all tubing used in irrigation systems to transport water at temperatures under 100° F. Other uses for which irrigation tube may be used, such as, piping for gas, air, and other fluids are not included in this standard.

103. *Standards and Specifications:*

(a) Unless otherwise specified, reference to this standard is to the latest revision as approved by the American Society of Agricultural Engineers. The use of the latest revisions of all other standards or specifications mentioned in this standard is intended.

(b) The standards and specifications cited herein are minimum requirements; dimensions and materials, unless otherwise specified, shall comply with these standards and specifications.

(c) Dimensions—(1) It is recommended that all tubing for lateral and main lines to be considered portable shall have outside diameters of 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, and 14 inches. Fractional sizes for these dimensions, outside of allowable tolerances, are not recommended. (2) Variations from specified dimensions for portable irrigation tubing shall not exceed the amounts prescribed in ASTM Specification: B235 for extruded tubing and B313 for welded tubing. (3) Permanent or buried irrigation lines that are not considered readily portable may have dimensions that are peculiar to the material used, unless restricted in other parts of this standard.

(d) Chemical composition: The tubing should conform to the requirements as to chemical composition prescribed in Table I of ASTM Specifications B-235 for extruded tubing, B-313 for welded tubing, and B-210 for drawn tubing.

104. *Compliance:*

(a) The manufacturer of irrigation tubing is responsible for complying with all the provisions of this standard and the identification of such tubing with its proper classification

(b) The dealer and/or the supplier of complete irrigation systems is responsible to the user of the system for the application of irrigation tubing supplied, wherein it is adequate for the system design and pressures. Safety devices to prevent the pressure from exceeding the test pressure shall be provided as agreed by the supplier and user.

105. *Materials:*

(a) The materials used† shall meet the mechanical and chemical requirements and tests of the latest revision of the respective specification of this standard.

(b) Should it be desired to use any material or method of manufacture not now covered by this standard, or which may be developed in the future, it is intended that the manufacturer shall provide details of design and construction which will be as safe as otherwise provided by the rules in this Standard. Where it is desired to use a material not included in

*This section lists one category and subhead. It is anticipated that other categories will be added when standards are proposed and deemed desirable.

†See Table I, Appendix A, for the specified mechanical properties of the aluminum alloys permitted herein.

this Standard, written application shall be made to the appropriate committee of the American Society of Agricultural Engineers, fully describing the proposed material preferably by an ASTM specification and including the proposed allowable stress (S value) for that material.

Part 1

Class 150—Hand Move Aluminum Irrigation Tubing

106. *Scope:*

Part 1 prescribes the minimum requirements for design, manufacture, and test for irrigation tubing to be used in systems where the operating pressure will not exceed 150 psi.

107. *Hydrostatic Tests:*

On the basis of a maximum operating pressure of 150 psi., all tubing must be capable of withstanding an internal hydrostatic test pressure of 450 psi. for two minutes without leaking.

108. *Thickness of Tubing:*

Minimum wall thickness is not a specification of this Standard, however, due to the relationship of wall thickness, diameter and mechanical properties of the material, the minimum wall thickness for each size of tubing and the specified yield strength of the material used must satisfy all of the following conditions:

(1) To prevent excessive denting in handling or field use, the tubing must have a denting factor equal or superior to that given in the following table for the pipe size under consideration:

Specified O.D. (inches)	Denting Factor
2	62
3	62
4	62
5	67
6	84
7	105
8	133
9	168
10	206

Denting factor: $Y_s \times (t)^2$

Where: Y_s=Specified yield strength of material (See Table I) psi

t=Specified wall thickness, inches

(2) The tubing must be capable of spanning thirty feet as a simple beam without permanent deflection or local buckling, when filled with water at zero pressure. The bending stresses (f) of aluminum alloy tubing that result shall not exceed the smaller of the two values found as follows:

(a) f=90 percent of the specified yield strength or,

(b) $f=1.57Y_s-[1.7(Y_s)^2/10{,}000{,}000](D/t)$

Where: Y_s=Specified yield strength (Table I)

D=Specified outside diameter, inches

t=Specified wall thickness, inches

Note:

(1) It is recommended that manufacturers of mechanical move systems use a safety factor of 2 in establishing their safety devices for protection of a torque load.

The following formula for aluminum alloy tubing will be used to compute the torque resistance:

Torque resistance$=11{,}500{,}000\ K\sqrt{D}\ (t)^{5/2}$

Where: K=Stiffening factor‡

D=Specified outside diameter, inches

t=Specified wall thickness, inches

(2) Theoretical Bursting Pressure:

The theoretical bursting pressure for the tubing shall be considered to be the pressure determined from the formula:

Where: $P=2S\,t/D$

Where: P=Bursting pressure in pounds per sq. inch

t=Specified wall thickness, inches

D=Specified outside diameter, inches

S=Allowable working stress as given in Table I (S values for welded and seamless) or those values guaranteed by manufacturer.

‡K=Stiffening factor. For extruded tubing, $K=1$. For welded tubing, $K=1$ until physical tests are completed and a new value assigned

Appendix A

TABLE I. ALLOWABLE WORKING STRESSES FOR ALUMINUM ALLOYS

Aluminum alloys		Minimum	Maximum allowable working stress (S value)	
Industry No.	ASTM No.	Yield (Y_s) (psi)	Welded tubing† tensile (psi)	Seamless tubing tensile (psi)
3003-H14	MIA	17,000*	14,000	20,000**
3003-H16	MIA	21,000**	14,000	24,000*
3003-H18	MIA	24,000**	14,000	27,000**
3004-H32	MGIIA	21,000*	23,000	28,000*
3004-H34	MGIIA	25,000*	23,000	32,000**
3004-H36	MGIIA	28,000**	23,000	35,000*
3004-H38	MGIIA	30,000**	23,000	38,000**
5050-H34	GIA	20,000*	18,000	25,000**
5050-H36	GIA	22,000**	18,000	27,000*
5050-H38	GIA	23,000**	18,000	29,000**
5052-H32	GR20A	23,000*	25,000	31,000*
5052-H34	GR20A	26,000*	25,000	34,000**
5052-H36	GR20A	29,000**	25,000	37,000*
5052-H38	GR20A	31,000**	25,000	39,000**
5086-H32	GM40A	28,000*	35,000	40,000*
5086-H34	GM40A	34,000*	35,000	44,000*
5086-H36	GM40A	38,000*	35,000	47,000*
5154-H32	GR40A	26,000*	30,000	36,000*
5154-H34	GR40A	29,000*	30,000	39,000**
5154-H36	GR40A	32,000*	30,000	42,000*
5154-H38	GR40A	34,000** (a)	30,000	45,000**
6061-T6	GS11A	35,000*	24,000	38,000† (c)
6063-T6	GS10A	25,000† (b)	——	30,000† (d)
6063-T31		28,000 (e)	——	30,000 (e)

Note: *ASTM Specification B313

**ASTM Specification B210

‡ASME B. & P.V. Code, Section IX, Par. QN-6(c)

†ASTM Specification B235

(a) B313 allows 35,000 psi for welded tubing

(b) B210 allows 28,000 psi for drawn tubing

(c) B210 allows 42,000 psi for drawn tubing

(d) B210 allows 33,000 psi for drawn tubing

(e) This is a new temper being used not currently covered by ASTM specifications but presently under consideration for approval. These values are tentative only until approved.

ASAE Tentative Standard: ASAE S262(T) Attachments No.3 and No.4

SPRINKLER IRRIGATION TECHNICAL DATA SHEET

Developed by ASAE Sprinkler Irrigation Research Committee in cooperation with the Sprinkler Irrigation Association, U. S. Farm Home Administration and U.S. Soil Conservation Service; adopted by ASAE January 1957.

FARM INFORMATION

Name of Owner ..... Address ..... Date .....

Section ..... Range ..... Township ..... County ..... State .....

IRRIGATION SYSTEM DESIGN AREA:

Topography — Include profile of proposed main pipeline locations. Give elevations of points around field boundaries, water level, pump locations, highest and lowest points in design area, and natural gas or electrical power line location.

Soils — Show predominating soil types and location on map.

Field Nos.	1	2	3	4	5
Available moisture-holding capacity ..... (in/ft)					
Intake rate (in/hr)					
Effective depth of soil (ft)					

WATER SUPPLY

Source Amount available ..... GPM ..... acre feet

Seasonal variation GPM ..... to GPM .....

Delivery scheduling .....

POWER SOURCE

Electrical Internal combustion engine ..... Fuel type ..... Other .....

If electrical give power phase ..... Voltage ..... HP limitations .....

LABOR AVAILABILITY

Hours of operation per day ..... Operation days per week .....

IRRIGATION REQUIREMENTS

DESIGN AREA				REQUIREMENTS		
Crops	Field No.	Acres	Effective root zone depth, feet	Moisture to be replaced each irrigation, inches	Peak moisture use rate, in per day	Peak use period irrigation frequency, days

Adopted and published by THE AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS, 420 Main Street, St. Joseph, Michigan

DESIGN AND SPECIFICATION INFORMATION

SYSTEM CAPACITY REQUIREMENTS

Minimum system capacity gpm

Field Nos.	1	2	3	4	5
Application rate (in/hr)					
Time of lateral operation per set (hrs)					
Depth applied per set (inches)					
Number of lateral sets per day (no.)					
Operation period to cover area (days)					
System capacity required (gallons)					
Water application efficiency (percent)					
Depth moisture replaced each irrigation (inches)					

SPRINKLER SELECTION

Application rate ..... in per hr. Sprinkler spacing on lateral ..... ft.
Lateral spacing on main line ..... ft. Sprinkler discharge ..... gpm
Diameter of circle covered ..... ft. Type ..... Nozzle sizes ..... " x ..... "
Required operating pressure ..... psi

LATERAL DESIGN

Lateral spacing on main line ..... ft. Sprinkler spacing on lateral ..... ft.
Lateral length ft. Area covered per lateral setting ..... acres.
No. sprinklers per lateral ..... Lateral discharge ..... gpm
No laterals required ..... , to cover design area in ..... days.
Pipe size required: Length ft. Diameter ..... in. Gage pipe .....
Length ft. Diameter ..... in. Gage pipe .....
Rise or fall (circle applicable condition) in lateral ..... ft.
Pressure loss in lateral due to friction ..... psi or ..... ft.
Pressure required (at main line) to operate lateral ..... psi or ..... ft.

MAIN LINE DESIGN

Portable or Permanent ..... Material: Steel ..... Aluminum ..... or Other .....
Main line length ft. Discharge capacity ..... gpm.
Rise or fall (circle one) in main line ..... ft.
Allowable head loss due to friction ..... ft.
Pipe sizes required ..... ft of ..... in pipe ..... gage.
..... ft of ..... in pipe ..... gage.
..... ft of ..... in pipe ..... gage.
Head loss due to friction ft. Outlet spacing on main line ..... ft.

SUPPLY LINE DESIGN (That portion of main line outside design area)

Supply line length ft. Discharge capacity ..... gpm.
Pipe size required ..... in. Friction head loss ..... ft.

TOTAL DYNAMIC HEAD REQUIREMENTS

Pressure required at lateral psi ..... ft.
Friction head loss in main line ..... psi ..... ft.
Friction head loss in supply line ..... ft.
Friction head loss on suction line ..... ft.
Elevation difference between pump and highest point of lateral line ..... ft.
Elevation difference between water source and center of pump ..... ft.
Miscellaneous friction head loss in special valves and fittings ..... ft. Total ..... ft.

PUMP REQUIREMENTS

Capacity ..... gpm at head ..... ft. Size ..... in.

PUMP SPECIFICATIONS

Type ..... Capacity ..... gpm. Efficiency ..... %, at ..... ft head
Rpm @ required discharge ..... Brake hp @ required discharge .....

POWER REQUIREMENTS

Water hp Efficiency ..... %. Brake hp ..... Rpm .....

POWER UNIT SPECIFICATIONS

Type ..... Make ..... Model ..... Size .....
Continuous hp rating ..... at ..... rpm
Cu-in displacement ..... Stroke ..... in.
Piston speed at design load ..... Bmep at design load ..... psi.
Type of power conversion ..... Speed ratio .....
Electric motor: Voltage ..... Phase ..... Rpm .....

ECONOMIC ANALYSIS OF IRRIGATION *

SYSTEM COST

ITEM	Quantity and unit	Unit cost, dollars	Total cost, dollars	Annual fixed cost
Well unit				
Pumphouse unit				
Power unit				
Pump unit				
Power line extension	ft.			
Main pipe line (complete with valves)	ft.			
Lateral pipe lines (complete)	ft.			
Sprinklers and risers	no.			
Special equipment:				
List:				
Total Material Costs				
Cash outlay for installation				
Farm costs, Labor				
Tractor use				
Other				
Total Farm Costs				
Total Cost				

LABOR COSTS

Moving laterals (per irrigation) ..... hrs. Moving mainline (per irrigation) ..... hrs.
Starting and stopping pump (per irrigation) ..... hrs.
Other time required (per irrigation) ..... hrs.
Total labor (per irrigation) ..... hrs. @ $ ..... per hour .....
Seasonal cost = Cost per irrigation ..... × No. of irrigations .....

INVESTMENT COST

Water development — (well, pond, sump, etc.) ..... $.....
Land development — (leveling, clearing) ....
Equipment ....
Materials ....
Labor ....
Other — (rights of way, legal and technical costs) ....
Total investment ..... $.....

ANNUAL FIXED COSTS

Annual depreciation of investment ..... $.....
Interest on average investment ....
Taxes — (irrigation equipment) ....
Insurance ....
Total fixed cost ..... $.....

ANNUAL OPERATING AND MAINTENANCE COST

Hours of operation per year .....
Fuel or electricity ..... $.....
Lubricating oils, grease, attendance ....
Labor, irrigating ....
Maintenance irrigation system ....
Total operating and maintenance costs ..... $.....
Total cost of irrigation = Fixed cost plus operating and maintenance costs ..... $.....
Cost per acre inch = Total cost of irrigation divided by total acre inches applied ..... $.....
Cost per irrigated acre = Cost per acre inch multiplied by inches applied ..... $.....

Remarks: .....

*Correctly this is a cost analysis, as an economic analysis would include other factors such as yield, return and indirect benefits. See bibliography for A.I.D. economic analysis reference.

Made by .....
Title .....
Date .....

MAP OF AREA TO BE IRRIGATED

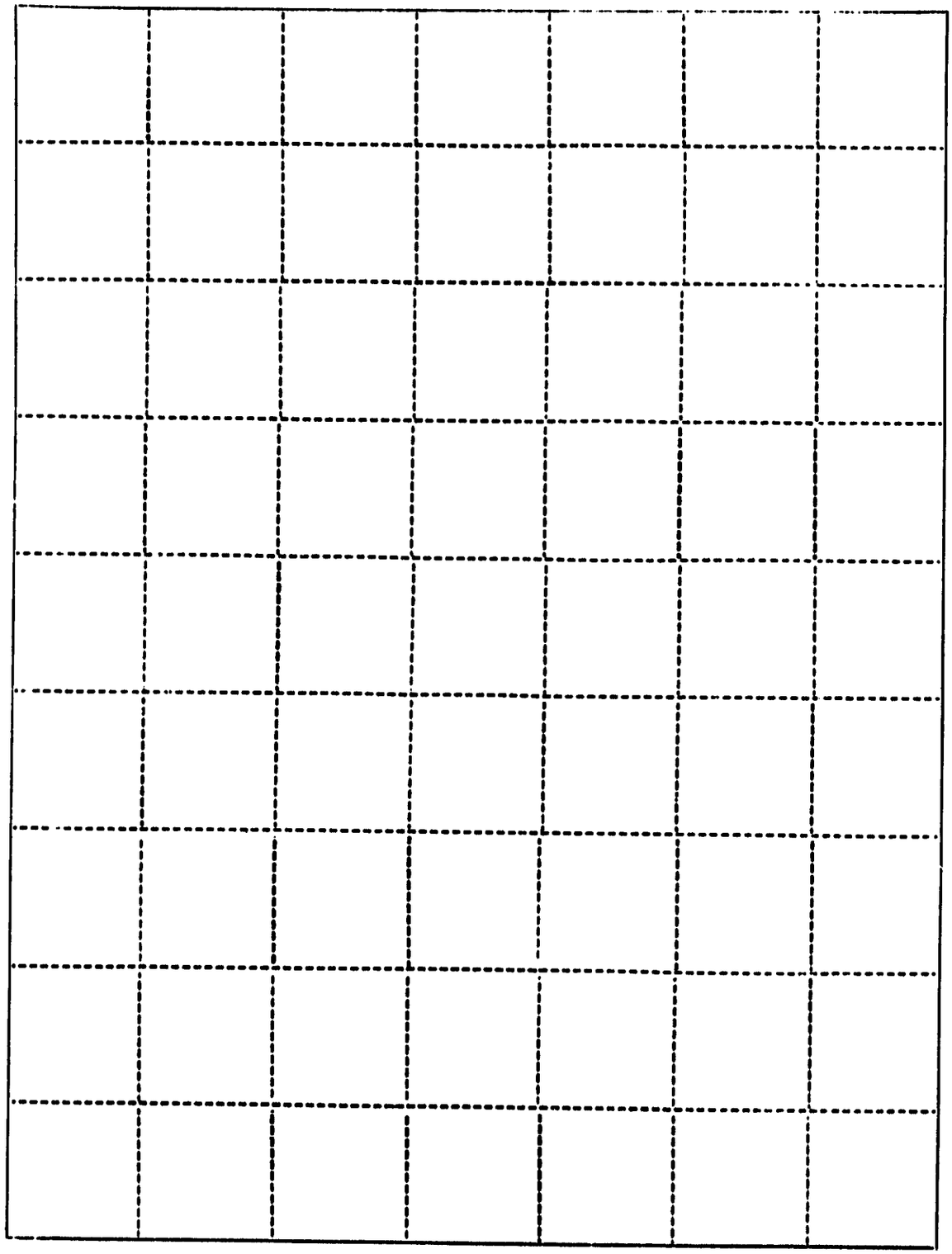


Table 22. English-Metric and Metric-English conversion factors

	Multiply	By	To Obtain
1. Length			
	Meters (m.)	3.281	Feet (ft.)
	Centimeters (cm.)	.3937	Inches (in.)
	Millimeters (mm.)	.0394	Inches (in.)
	Feet (ft.)	.305	Meters (m.)
	Inches (in.)	2.54	Centimeters (cm.)
	Inches (in.)	25.4	Millimeters (mm.)
	Miles (mi.)	1.609	Kilometers (km.)
	Kilometers (km.)	.621	Miles (mi.)
2. Pressure			
	Pounds per square inch (psi)	2.31	Feet of water (62°F)
		.703	Meters of water (62°F)
		.0703	Kilogram per sq. cm. (Kg/cm^2)
		.068	Atmospheres (Atmos.)
		2.036	Inches Mercury (32°F)
	Feet of water at 62°F	.433	Pounds per sq. in. (PSI.)
		.0305	Kg. per sq. in.
		.029	Atmospheres
	Meters of water at 62°F	1.422	Pounds per sq. in.
		.10	Kg. per sq. cm.
		.097	Atmospheres
	Atmospheres	14.7	Pounds per sq. in.
	Kilograms per sq. cm.	14.22	Pounds per sq. in.
		10.00	Meters of water
3. Volume			
	Cubic feet	7.48	U.S. gallons (U.S. Gal.)
		6.23	Imperial gallons (Imp. Gal.)
		28.3	Liters (Lt.)
		.0283	Cubic feet (ft^3)
	U.S. Gallons	.1337	Cubic feet
		.833	Imperial gallons

Table 22. English-Metric and Metric-English conversion factors (Cont.)

Multiply	By	To Obtain
U.S. Gallons (Cont.)	3.785	Liters
	.0038	Cubic meters (m^3)
Cubic Meters	35.315	Cubic feet
	264.2	U.S. gallons
	1000	Liters
U.S. Quarts	.9463	Liters
Acre feet	1233.49	Cubic meters
	43,560.	Cubic feet
	325,851.	Gallons
4. Units of Flow		
Cubic feet per sec.	448.8	U.S. gallons per minute
	373.7	Imperial gallons per minute
	28.32	Liters per second
U.S. gallons per minute	.00223	Cubic feet per second
	.0631	Liters per second
	.833	Imperial gallons per minute
Imperial gallons per minute	1.2	Gallons per minute
	.0758	Liters per second
Liters per second	.0353	Cubic feet per second
	15.850	U.S. gallons per minute
	13.199	Imperial gallons per minute
Cubic meters per hour	.0098	Cubic feet per second
	4.403	U.S. gallons per minute
	3.666	Imperial gallons per minute
5. Area		
Acres	.4047	Hectares (ha.)
	43.560	Square feet
	4047.	Square meters
	.00156	Square miles
Hectares	2.471	Acres
	107,639.	Square feet
	10000	Square meters
	.00386	Square miles

6. Temperature

$F^o = \frac{9}{5} (C^o) + 32$

$C^o = \frac{5}{9} (F^o) - 32$

Table 23. Common fractions of an inch to millimeters*

2NDS	4THS	8THS	16THS	32NDS	64THS	DECIMAL INCH 6 PLACE	DECIMAL INCH 3 PLACE	MILLIMETERS
					1	0.015625	0.016	0.396875
				1		.031250	.031	0.793750
					3	.046875	.047	1.190625
			1			.062500	.062	1.587500
					5	.078125	.078	1.984375
				3		0.093750	0.094	2.381250
					7	.109375	.109	2.778125
		1				.125000	.125	3.175000
					9	.140625	.140	3.571875
				5		.156250	.156	3.968750
					11	0.171875	0.172	4.365625
			3			.187500	.188	4.762500
					13	.203125	.203	5.159375
				7		.218750	.219	5.556250
					15	.234375	.234	5.953125
	1					0.250000	.250	6.350000
					17	.265625	.266	6.746875
				9		.281250	.281	7.143750
					19	.296875	.297	7.540625
			5			.312500	.312	7.937500
					21	0.328125	.328	8.334375
				11		.343750	.344	8.731250
					23	.359375	.359	9.128125
		3				.375000	.375	9.525000
					25	.390625	.391	9.921875
				13		0.406250	.406	10.318750
					27	.421875	.422	10.715625
			7			.437500	.438	11.112500
					29	.453125	.453	11.509375
				15		.468750	.469	11.906250
					31	0.484375	.484	12.303125
1						.500000	.500	12.700000
					33	.515625	.516	13.096875
				17		.531250	.531	13.493750
					35	.546875	.547	13.890625
			9			0.562500	.562	14.287500
					37	.578125	.578	14.684375
				19		.593750	.594	15.081250
					39	.609375	.609	15.478125
		5				.625000	.625	15.875000
					41	0.640625	.641	16.271875
				21		.656250	.656	16.668750
					43	.671875	.672	17.065625
			11			.687500	.688	17.462500
					45	.703125	.703	17.859375
				23		0.718750	.719	18.256250
					47	.734375	.734	18.653125
	3					.750000	.750	19.050000
					49	.765625	.766	19.446875
				25		.781250	.781	19.843750
					51	0.796875	.797	20.240625
			13			.812500	.812	20.637500
					53	.828125	.828	21.034375
				27		.843750	.844	21.431250
					55	.859375	.859	21.828125
		7				0.875000	.875	22.225000
					57	.890625	.891	22.621875
				29		.906250	.906	23.018750
					59	.921875	.922	23.415625
			15			.937500	.938	23.812500
					61	0.953125	.953	24.209375
				31		.968750	.969	24.606250
					63	.984375	.984	25.003125
2	4	8	16	32	64	1.000000	1.000	25.400000

* Basis: 1 Inch = 25.4 millimeters