IRRIGATION MANUAL FOR BARBADOS

IICA

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Preface

Barbados shall soon be embarking on more extensive irrigated agriculture, especially for vegetable crops. The need was felt to integrate existing climatic, soil and economic information in Barbados to produce a working guide for irrigation under Barbadian conditions. The guide is oriented by basic principles of soil water management and conservation,crop water needs, sprinkler and trickle irrigation and cost and production economic analysis.

Existing information has been used with the hope that further research will improve the quality of the climatic and soils data and thus improve the value of this guide.

This effort is a result of collaboration between staff members of the IICA Office in Barbados and the Land and Water Use Unit of the Ministry of Agriculture, Food and Consumer Affairs of Barbados, and it is hoped that it shall serve as a useful guide to farmers and extension agents.

Warren Forsythe
Director of the IICA Office in Barbados
December, 1980

Acknowledgement

It is difficult to enumerate the types of participation of all those who contributed to this document because of the many different ways in which they cooperated. Nonetheless, the principal collaborators names appear in the paper which form part of each chapter. I would like to take this opportunity to acknowledge their work and to draw attention to the obvious fact that without their efforts a collection such as this would not be possible. It is also important to stress the invaluable work of Dr. Warren Forsythe, Director of the IICA Office in Barbados who has given advice, support and commentaries on the technical documents.

Constant dedicated secretarial assistance has been essential for this manual. I have had the willing collaboration of Angela Parris who ably fulfilled these requirements. Finally, I wish to acknowledge the Inter-American Institute of Agricultural Sciences which made this manual possible.

Victor Ojeda, Agricultural
Economist Specialist, Editor.

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CHAPTER 1

WATER REQUIREMENTS OF PLANTS AND SOIL WATER MANAGEMENT

Warren M. Forsythe

Climate in relation to evaporation and water use by plants

Plants growing in a wet soil (adequately wet but not flooded) extract water from it much in the same way that a wet wick partially placed in a bottle of water extracts water from the bottle. Plants, like the wet wick, permit evaporation and this is affected by temperature, radiation, relative humidity and wind. Plants growing in a wet soil free of salinity, enjoy the Maximum Possible Crop Water Consumption (MPCWC). Crops have individual values of MPCWC. The MPCWC can be compared to the evaporation from water in a class A open pan, under the same weather conditions as the crop. These coefficients for fully developed crops can vary from 20% to 110% of pan evaporation. Most crops studied have coefficients between 80% and 110%.

Crop water use in relation to field practices and plant age

As a wet soil dries, plants have greater difficulty in extracting water and consumption drops below the maximum to almost nothing when the plant is permanently wilted. Thus if one irrigates a crop when it begins to show signs of permanent wilt, less water would be used than if irrigation were done more frequently to keep the soil wet. However, there will be a large loss in yield as shall be seen in a later section.

A bare wet soil that is well drained allows the evaporation of approximately 40% of the MPCWC of crops with a coefficient of one; in other words approximately 40% of class A pan evaporation. Thus the soil of a field covered with actively growing grass would be drier than the neighbouring bare soil, a few days after receiving the same irrigation.

A complete cover with a dead mulch further reduces wet soil evaporation by about 43%. The resulting coefficient would be 40% x 43% =17%. However, the effect of the mulch is reduced as the soil dries. Thus for mulching to be effective in reducing soil evaporation loss, it should be present when the soil is initially wet.

A recently planted wet field will permit evaporation like a bare soil but as the crop covers the soil, the water consumption increases to a maximum. Crops that develop mature leaves and leaf-drop with age reduce their water consumption after the maximum period. Table 1.1 and Figures 1.1 and 1.2 show how the crop water consumption coefficient changes with age for some crops. For example kidney beans under clean cultivation start at 40%, increase to a maximum of 96% and fall off to 40% at the end of the growing season. Intermediate values can be read-off from Figures 1.1 and 1.2. Coefficients for other crops can be obtained from your extension agent as information appears as a result of research on other crops. The Table also shows how a 100% mulch cover can reduce evaporation losses. Until more information exists on horticultural crops, it is recommended that the values for kidney beans be used. If there is no leaf-fall, the maximum value will continue until harvest.

Dependable rainfall in Barbados

It is important for the farmer to know what are the chances that a certain minimum of rain will fall for a particular month or week, which will give a good crop. This minimum should occur 3 out of 4 years (75% dependability)and is called 75% dependable rainfall. Average rainfall figures tend to be only 50% dependable, not enough for economic farm planning.

FIGURE 1.1
CROP WATER CONSUMPTION
COEFFICIENT (%) AND CROP AGE

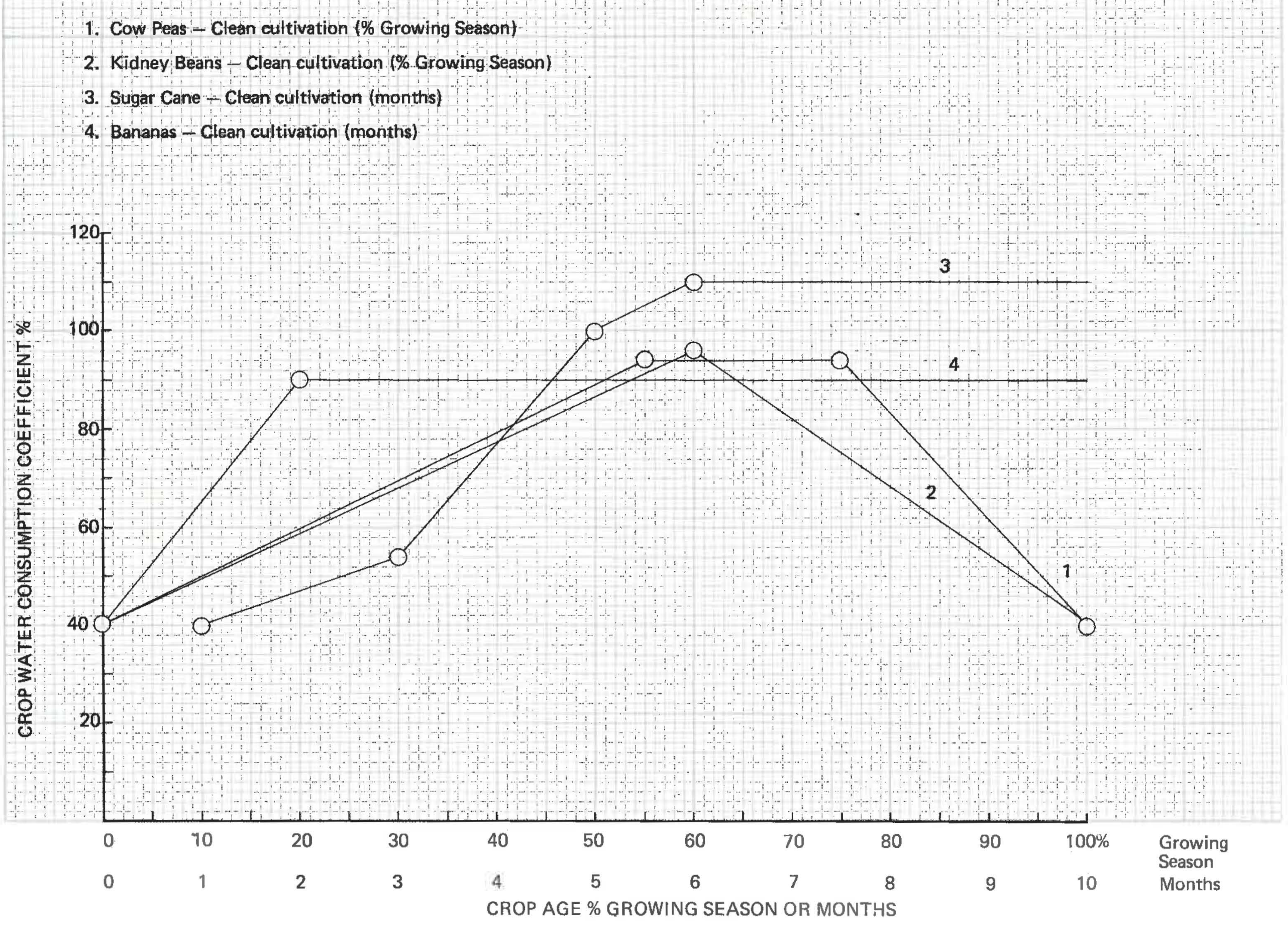


FIGURE 1.2
CROP WATER CONSUMPTION COEFFICIENT (%) AND CROP AGE

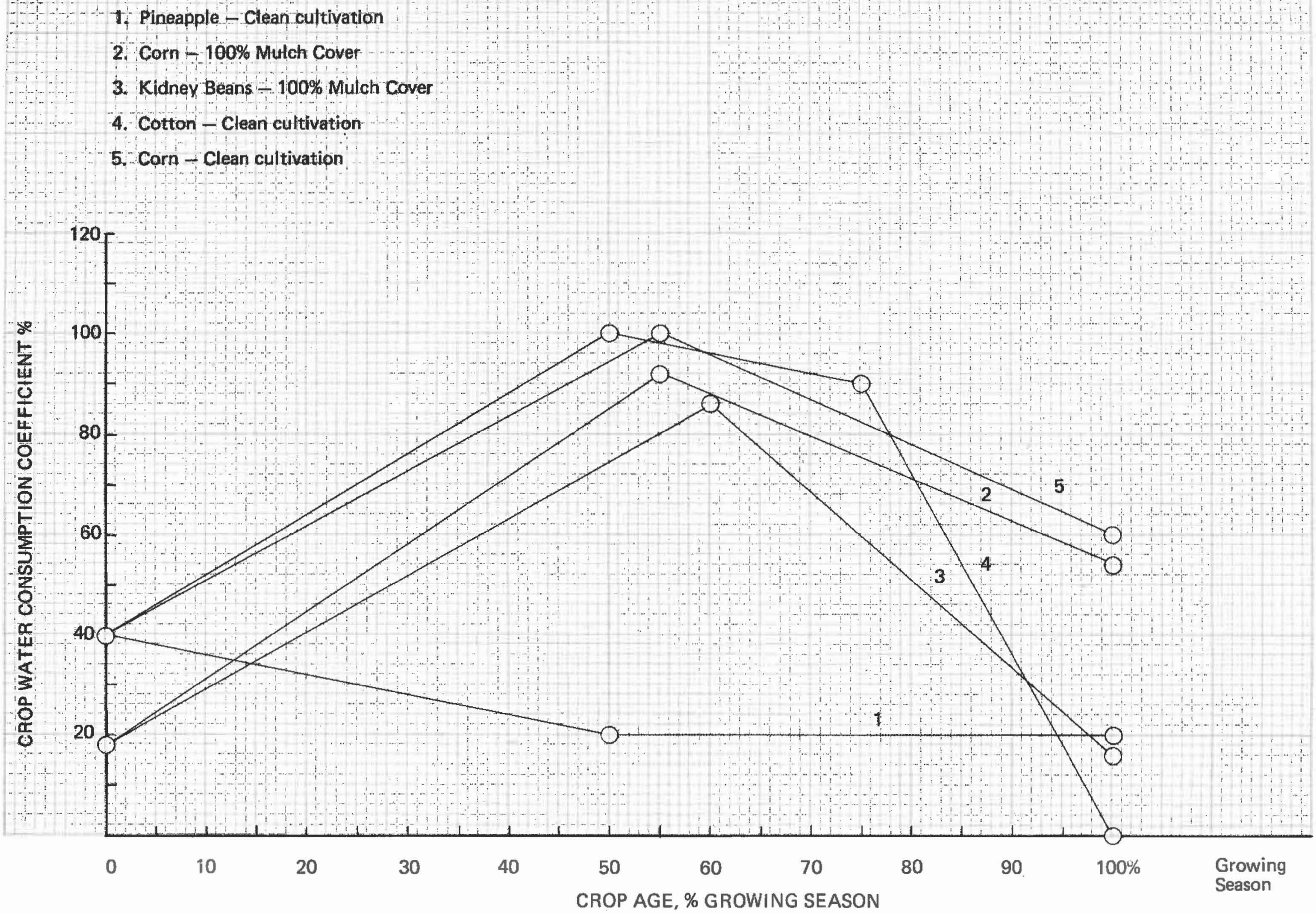
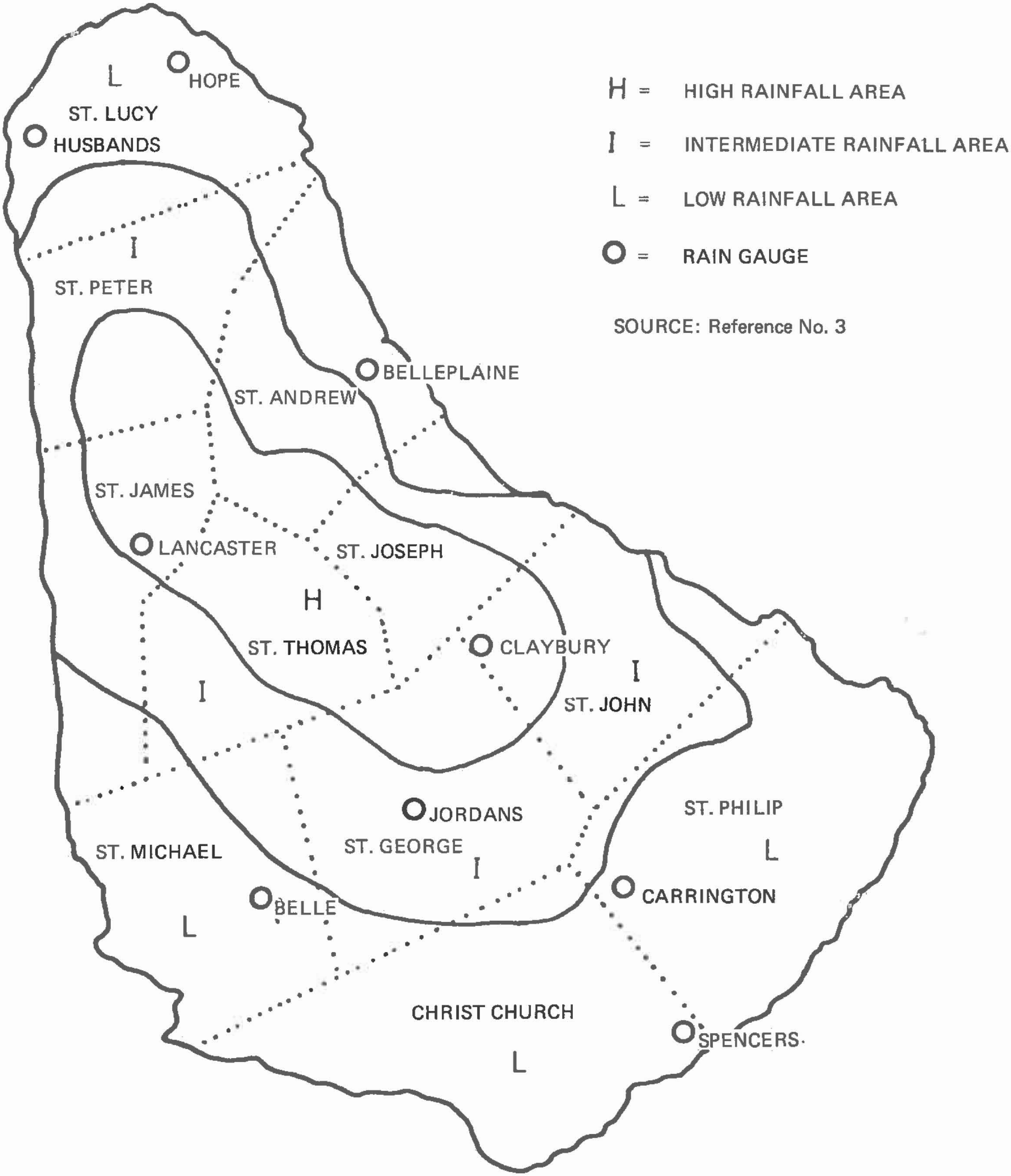


FIGURE 1.3

BARBADOS RAINFALL ZONES



SOURCE: Reference No. 3

Tables 1.2a to 1.2i show 75% dependable rainfall for various weather situations in Barbados. The original monthly rainfall is given here on a weekly basis, since this is more practical for planning operations. Figure 1.3 shows the locations of the weather stations within three rainfall zones, so that a location in a particular zone would use the data of the nearest station within that zone.

The MPCWC for a given week would be the maximum amount of water needed to enter in the root zone of the plant, assuming that there is no rainfall that week and that the crop has a Crop Water Consumption Coefficient of 100%. However, if we consider the 75% dependable rainfall expected for that week, part of the MPCWC would be satisfied by this rainfall, so that the remaining water requirement would be also 75% dependable. This means that for the particular week in question the plant would need up to this quantity of water 3 out of 4 years. This quantity will be called the 75% Maximum Crop Water Needs. For 1 out of 4 yeras the water requirement would be greater, that is, up to the value of the MPCWC, but the extra cost to provide this extra water should be justified by the additional yield. We may therefore say.

75% Maximum Crop Water Needs (MCWN) = Maximum Possible Consumption (MPCWC) - 75% Dependable Rainfall.

Crop Water needs in Barbados changes with location and time of year

Tables 1.2a to 1.2i show how MPCWC, 75% DR and 75% MCWN change for different locations of Barbados and different times of the year. The values of 75% MCWN are multiplied by values of the Crop Water Consumption Coefficient/100, (Table 1.1 and Figures 1.1 and 1.2) for the planning of weekly water needs of a given crop. For example, if we wish to know what weekly supply would be 75% reliable for recently planted kidney beans(0% of the growing season) during week No. 14 (April) for the Lancaster area, this would be 40/100 x 24.5 = 9.8 mm of water. For kidney beans at 60% of its growing season this would be 96/100 x 24.5 = 23.5 mm. The value of the Crop Water Consumption Coefficient for 40% of its growing season can be read-off from graph No. 2 in Figure 1.1 and this is 77%.

The weekly water supply for kidney beans at 40% of its growing season would then be 77/100 x 23.5 = 18.1mm.

The value of the Crop Water Consumption Coefficient for 80% of its growing season is again read from the graph and is 68%.

The weekly water supply for kidney beans at 80% of its growing season would then be 68/100 x 24.5 = 16.7 mm.

It is important that the previously calculated weekly supplies would be 75% reliable. This means that such a supply would on the average be sufficient 3 out of 4 years. If we wanted a weekly supply which would be 100% reliable then the value of MPCWC for week No. 14 would be used instead of 75% MCWN and this would be 33mm. This value would be multiplied by the Crop Water Consumption Coefficient as above.

Week No. 14 also has the highest average weekly MPCWC for the year and the Crop Water Need derived from this figure is used to estimate the capacity of the sprinkler system to deliver this amount of water to the root zone.

Assuming that the efficiency of a sprinkler system is 75%, then the pumping capacity of the system to provide flow to the nozzles would be MPCWC/0.75 for the week.

Effect of bare soil and mulching on the MPCWC and the MCWN

If we have a bare soil at field capacity the values of MPCWC are multiplied by 0.4. The 75% MCWN will thus be reduced. If we examine the tables we shall see that weeks that did not have an excess of water under full crop cover, now have one, and the soil will begin to moisten. If, in addition, the bare soil is completely covered with a mulch, then the values of MPCWC are multiplied by 0.17. This extends even further, the period of weeks with excess water, when the soil can be moistened by accumlated rainfall. This explains the practice in Barbados where a bare soil or a bare soil with mulch will allow the soil to moisten and permit earlier planting dates. One must remember however, that when the plants are fully developed the MCWN assumes its original value.

Weekly rainfall logging

It is possible to have a rain gauge on the farm and compare the rain fallen in a given week with the 75% DR. According to the 75% MCWN one would plan to irrigate, so that 24.5 mm reached the root zone during week No. 14. Thus the application would be 24.5/Efficiency. Sprinkler irrigation efficiency is rated around 75%. If the rainfall was more or less that 8.5 mm, the 75% DR, then the adjustment could be made in the application for week No. 15.

Soil moisture needs of crops

Not only do crops need a certain volume of water per day for transpiration, but they need, that the moisture in the soil is at a certain degree of wetness. A drop of water touching a dry soil clod is soon sucked up by the clod. Dry soil attracts water and exerts a suction on the water, which can be expressed as bars as in pressure. (1 Bar = 100 centibars = 1000 millibars).

The drier the soil the greater the suction. A wet soil at field capacity has a suction of 0.1 to 0.3 bars and a soil, that has been dried by plants until they are the permanent wilting stage, has a suction of around 15 bars. Figure 1.4 shows, in general, how the suction at which a soil is irrigated affects crop yields.

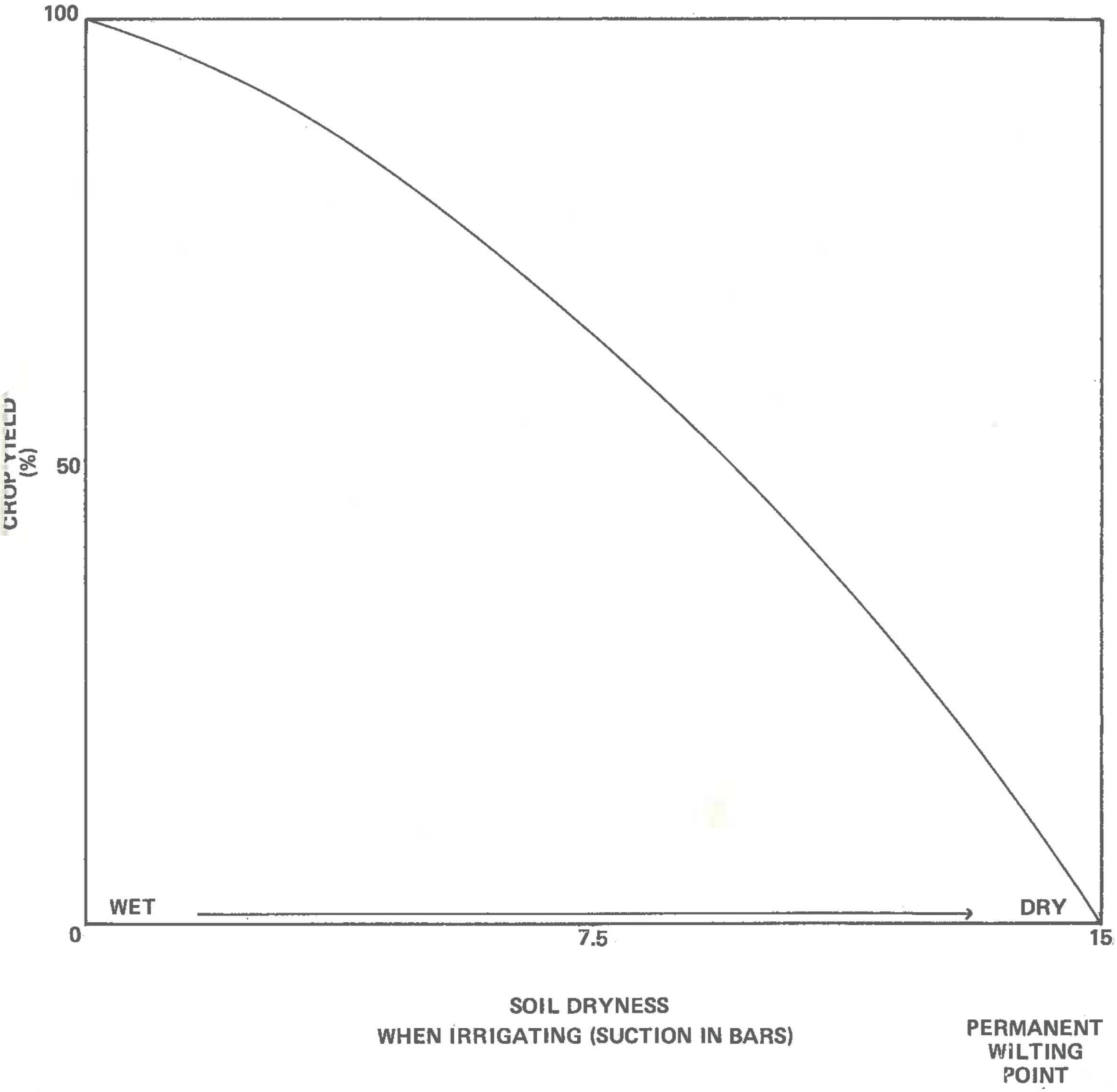
Measuring soil wetness

Soil wetness has been estimated by feel but this method is not sensitive enough for efficient water use. The soil moisture percentage can be estimated by drying the soil in an oven at 105°C, but the method is too laborious for field monitoring during agricultural production. The electrical resistance of blocks of gypsum or nylon, change with soil moisture and this equipment is suitable for monitoring. The tensiometer is a popular instrument used to measure soil wetness since it measures the suction. Figure 1.5 shows a tensiometer which is basically a vacuum gauge water meter which makes contact with soil water by means of a porous ceramic tip. The tensiometer can be used to a dryness of 0.8 bars (80 centibars) suction, which is a suction value at which the irrigation of many horticultural crops is recommended.

Hot water wets the soil

If one obtains a strip of dry blotting paper and puts a few drops of water on the upper end, one notices that the wetted portion ends abruptly,

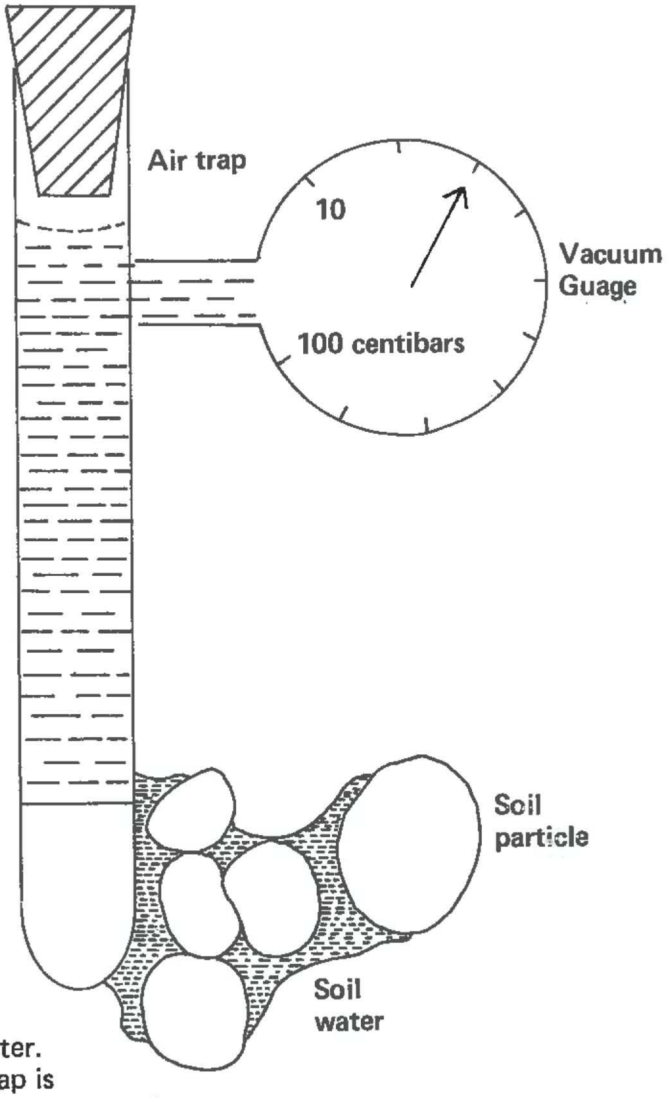
FIGURE 1.4



100
50
0
CROP YIELD (%)
WET
DRY
7.5
15
SOIL DRYNESS
WHEN IRRIGATING (SUCTION IN BARS)
PERMANENT WILTING POINT

FIGURE 1.5

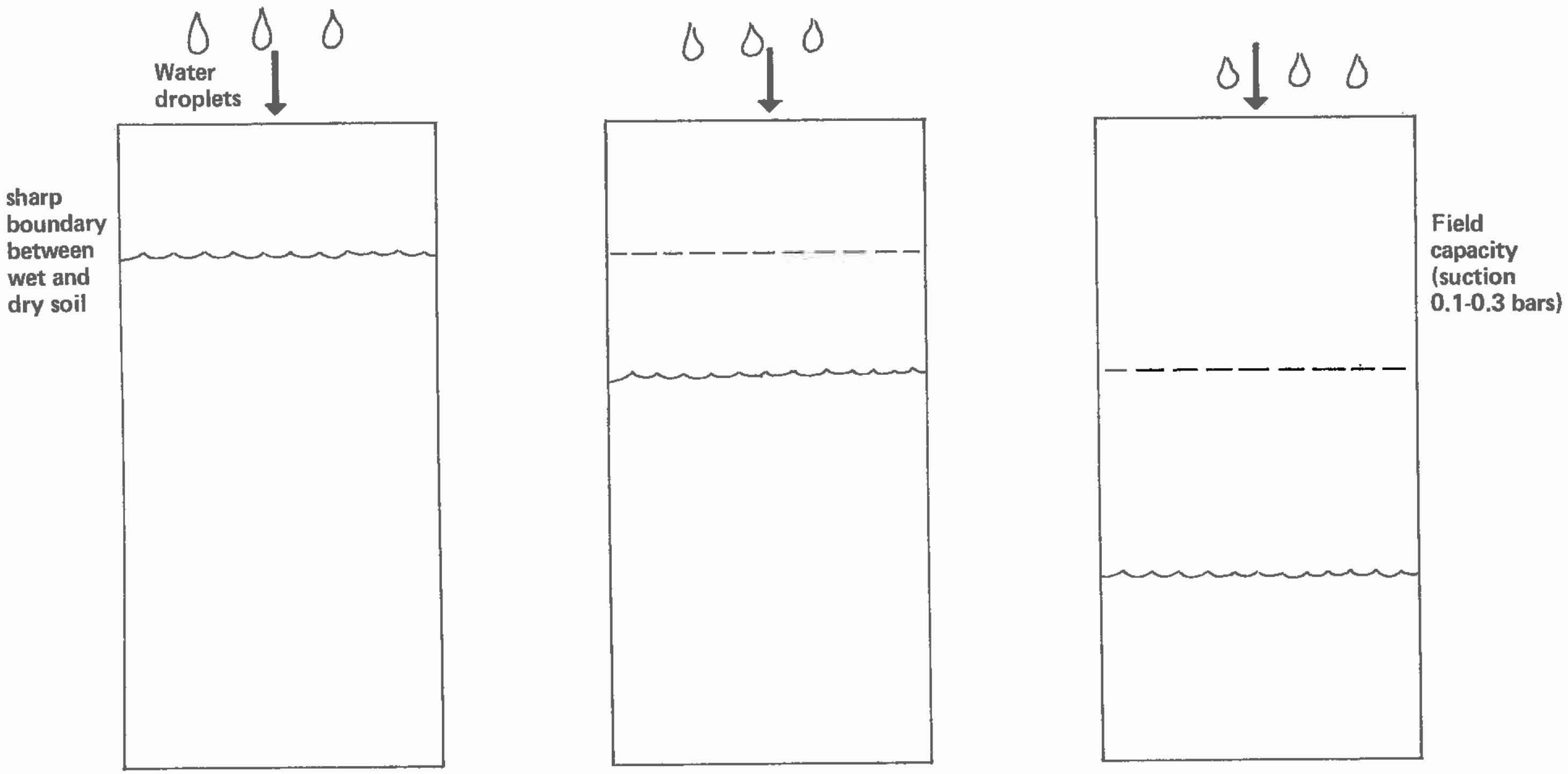
TENSIOMETER



Ceramic tip with fine pores permits contact with water in moist well-drained soil. No soil nor air bubbles enter. Air found in the air trap is due to air previously dissolved in the water forming bubbles. This can be remedied by refilling the tube.

FIGURE 1.6

HOW WATER WETS THE SOIL



and the wetting front moves downwards slowly. If more water is added the wetting front advances downwards and then stops once more to a slow downward movement. Figure 1.6 illustrates this process. Water enters and wets a dry soil in a similar manner. When the wetting front in the soil reaches the slow downward movement stage, the wet soil is said to be at field capacity and the soil has a wetness of around 0.1 to 0.3 bars of suction.

Storage in the soil, of water that plants can use

Plants extract water from the soil and dry it until they wilt permanently. The soil suction at this point is around 15 bars If the soil is initially wet at field capacity, (0.1 to 0.3 bars) then the plant begins to extract water which is easily available up to about 1 to 2 bars of suction and this supports active growth. The plant continues to extract water which is increasingly more difficult to obtain but will maintain the plant alive with some limited growth. When the plant extracts water until it wilts permanently, the plant dies. The soil moisture is then at the 15 bar level. We can identify soil water that supports active growth and soil water that supports plant survival. In agricultural production we are interested in active growth and we can separate two types of water stored in the soil.

1) Soil water storage for growth and survival = Moisture % at Field Capacity (0.1 to 0.3 bars) less the % at the Permanent Wilting Point (15 Bars).
2) Soil water storage for active growth = Moisture % at Field Capacity (0.1 to 0.3 bars) less the % at 1 to 2 bars of Suction.

Storage capacity of some Barbadian soils

Table 1.3 shows the water storage capacity of some Barbadian soils.

Storage is given in two forms 1) For growth and survival and 2) For active growth using 1 bar suction as the limit. The Black association has the greatest storage capacity of the soils studied, whereas the Red Brown association has the lowest capacity. In spite of the fact that both soils have clay texture, the Black association has a higher moisture holding capacity than the Red Brown association because the former is a montomorillonitic clay while the latter is a kaolonitic clay.

Plant root depth and storage capacity

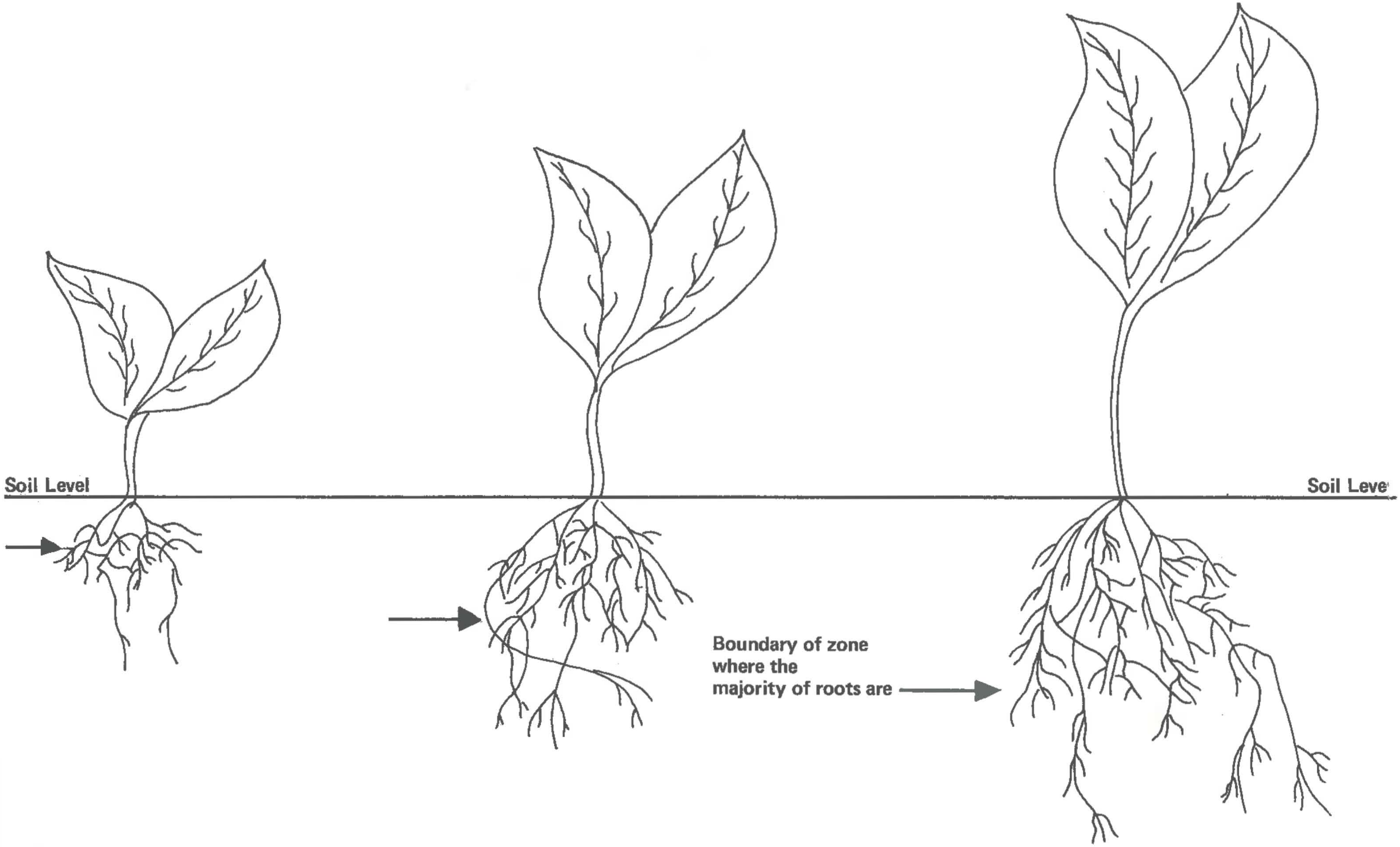
The greater the root depth, the larger the soil depth that can be used for storage of water. A practical guide to estimate soil depth is that which contains the majority of the roots. Figure 1.7 illustrates this point. Note that young plants with a small root depth will have a small soil storage capacity to use. Although roots of young plants do not penetrate deeply into the soil, initial irrigation should aim to wet all the soil expected to be used during the growing season, so that the young roots may be permitted to develop and penetrate the soil to the maximum as quickly as possible. Table 1.3 shows how the moisture storage capacity is calculated for given root depth.

The effect of soil storage capacity on how often you irrigate

Let us consider some examples. For the Lancaster area during April for a fully developed crop with a Crop Water Consumption Coefficient of 100%, the Crop Consumption for a week would be 24.5 x 100/100 = 24.5 mm. This is equivalent to 24.5/7=3.5mm/day. If a soil such as No. 34 is to be found in the region and the root zone is 12 ins (30.4cm) with a water storage for active growth of 50.8 mm, then the frequency of irrigation is 50.8/3.5 = 14 days (to the nearest day). If the crop had a 12" root zone on Soil 46 the storage would be 28 mm and the frequency of irrigation would be 28/3.5 = 8 days. (That is, every 8 days.).

FIGURE 1.7

ROOT DEPTH AND STORAGE



Soil No. 34	Storage for active growth in 6 in. zone when the majority of roots are (15.2 cm) root depth = 1 in. (2.54 cm) water. Storage for active growth in 12 in. zone when the majority of roots are (30.4 cm) root depth = 2 in. (5.08 cm) water.
Soil No. 46	Storage for active growth in 6 in. zone when the majority of roots are (15.2 cm) root depth = 0.56 in. (1.4 cm) water. Storage for active growth in 12 in. zone where the majority of roots are (30.4 cm) root depth = 1.12 in. (2.8 cm) water.

If there is no rainfall during April, then Crop Consumption for a week would be 33 x 100/100 = 33 mm. This is equivalent to 33/7 = 4.7 mm/day. Irrigation frequency on 12" of Soil 34 would be 50.8/4.7 = 11 days. On the other hand irrigation frequency on Soil 46 would be 28/4.7 = 6 days.

For the Spencer area during April, Crop Consumption for a week would be 32.7 x 100/100 = 32.7 mm. This is equivalent to 32.7/7 = 4.7 mm/day. If a soil such as No. 34 is to be found in the region and the root zone is 12 ins with a water storage of 50.8 mm, then the frequency of irrigation is 50.8/4.7 = 11 days. If the crop had a 12" root zone on Soil 46 the storage would be 28 mm and the frequency of irrigation would be 28/4.7 = 6 days. If there is no rainfall during April, then Crop Consumption for a week would be 37.3 x 100/100 = 37.3 mm. This is equivalent to 37.3/7 = 5.3 mm/day. Irrigation frequency on 12 inches of Soil 34 would be 50.8/5.3 = 10 days. On the other hand irrigation frequency on 12 inches of Soil 46 would be 28/5.3 = 5 days

Thus we see that during April irrigation frequency can vary from every 14 days to every 5 days depending on the soil and rainfall. June and July are examples of months that still need irrigation although the frequencies will be lower.

The effect of soil storage capacity on how much water to apply during irrigation

Since the storage of 12 ins of Soil 34 is 50.8 mm, this quantity of water will have to enter the root zone during irrigation. Because sprinkler irrigation is approximately 75% efficient, more water will have to leave the nozzle so that 50.8 mm reaches the root zone and this is 50.8/0.75 = 67.7mm. Thus, one should plan to apply 67.7 mm of water during an application.

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TABLE 1.1.

CROP WATER CONSUMPTION COEFFICIENT (%) AND CROP AGE

CROP	CULTIVATION PRACTICE	% OF GROWING SEASON* OR MONTHS, AND % COEFFICIENT			
Corn	clean cultivation	0;40	55; 100	100;60	
Corn	100% mulch cover	0;17	55; 91	100;55	
Kidney beans	clean cultivation	0;40	60; 96	100;40	
Kidney beans	100% mulch cover	0;17	60; 88	100;17	
Cotton	clean cultivation	0;40	50;100	75;90	100;0
Sugar cane	clean cultivation	1 month; 40	3 months;54	5 months;100	5+months;110
Pineapple	clean cultivation	0;40	50;20	100;20	
Complete grass cover	clean cultivation	0;40	complete cover;105		
Bananas	clean cultivation	0 months; 40	2+months; 90		
Cow peas	clean cultivation	0;40	55;94	75;94	100;40

*Growing season includes leaf-maturation and leaf-fall.

WEEKLY CROP WATER NEED TABLE (mm of water)

TABLE 1.2a

BELLE STATION ALTITUDE:37.80m (124ft)

MONTH	JANUARY				FEBRUARY				MARCH				
WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13
MPCWC	28.2	28.2	28.2	28.2	28.2	28.5	28.5	28.5	32.5	35.6	35.6	35.6	35.6
75% DR	8.9	8,9	8.9	8.9	8.1	7.4	7.4	7.4	5.8	4.8	4.8	4.8	5.3
75% MCWN	19.3	19.3	19.3	19.3	20.1	21.1	21.1	21.1	26.7	30.8	30.8	30.8	30.3

MONTH	APRIL				MAY					JUNE			
WEEK	14	15	16	17	18	19	20	21	22	23	24	25	26
MPCWC	37.6	37.6	37.6	37.6	36.8	36.6	36.6	36.6	35.8	34.8	34.8	34.8	34.8
75% DR	7.9	7.9	7.9	7.9	56.1	64.3	64.3	64.3	73.7	86.4	86.4	86.4	76.5
75% MCWN	29.7	29.7	29.7	29.7	19.3 *	27.7 *	27.7 *	27.7 *	37.9 *	51.6 *	51.6 *	51.6 *	41.7 *

MONTH	JULY				AUGUST				SEPTEMBER				
WEEK	27	28	29	30	31	32	33	34	35	36	37	38	39
MPCWC	34.8	34.8	34.8	34.8	34.3	34.0	34.0	34.0	32.8	29.7	29.7	29.7	29.7
75% DR	16.3	16.3	16.3	16.3	22.4	24.6	24.6	24.6	24.4	23.9	23.9	23.9	23.9
75% MCWN	18.5	18.5	18.5	18.5	11.9	9.4	9.4	9.4	8.4	5.8	5.8	5.8	5.8

MONTH	OCTOBER				NOVEMBER					DECEMBER			
WEEK	40	41	42	43	44	45	46	47	48	49	50	51	52
MPCWC	26.2	26.2	26.2	26.2	27.2	28.2	28.2	28.2	28.2	29	29	29	29
75% DR	28.2	28.2	28.2	28.2	23.9	21.1	21.1	21.1	18.8	13.5	13.5	13.5	13.5
75% MCWN	2.0 *	2.0 *	2.0 *	2.0 *	3.3	7.1	7.1	7.1	9.4	15.5	15.5	15.5	15.5

MPCWC = Maximum Crop Water Consumption (or Potential Evapotranspiration),when soil is at field capacity (moist)

75% DR= Dependable Rainfall at 75% certainty

75% MCWN = Maximum Crop Water Needs at 75% certainty (Atmospheric Water Balance) when soil is at field capacity (moist)

NOTE: The values in the tables are multiplied by the crop water consumption coefficient/100, for each individual crop according to the crop and its age.

* 'EXCESS' - No irrigation needed.
When soil is drier than field capacity MPCWC and MCWN are reduced.

TABLE 1.2b

WEEKLY CROP WATER NEED TABLE (mm of water)

BELLEPLAINE STATION ALTITUDE: 6.10 m (20ft)

MONTH	JANUARY					FEBRUARY				MARCH			
WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13
MPCWC	28.2	28.2	28.2	28.2	28.5	28.5	28.5	28.5	32.5	35.6	35.6	35.6	35.8
75% DR	9.3	9.3	9.3	9.3	8.0	7.1	7.1	7.1	5.1	3.6	3.6	3.6	3.9
75% MCWN	18.9	18.9	18.9	18.9	20.5	21.4	21.4	21.4	27.4	32.0	32.0	32.0	31.9

MONTH	APRIL				MAY					JUNE			
WEEK	14	15	16	17	18	19	20	21	22	23	24	25	26
MPCWC	37.3	37.3	37.3	37.3	36.6	36.6	36.6	36.6	35.8	34.8	34.8	34.8	34.8
75% DR	6.1	6.1	6.1	6.1	7.3	7.5	7.5	7.5	8.5	10	10	10	10.7
75% MCWN	31.2	31.2	31.2	31.2	29.3	29.1	29.1	29.1	27.3	24.8	24.8	24.8	24.1

MONTH	JULY				AUGUST				SEPTEMBER				
WEEK	27	28	29	30	31	32	33	34	35	36	37	38	39
MPCWC	35.1	35.1	35.1	35.1	34.3	34.0	34.0	34.0	32.8	29.7	29.7	29.7	29.7
75% DR	15.1	15.1	15.1	15.1	22.6	25.6	25.6	25.6	26.7	29.5	29.5	29.5	29.5
75% MCWN	20.0	20.0	20.0	20.0	11.7	8.4	8.4	8.4	6.1	0.2	0.2	0.2	0.2

MONTH	OCTOBER				NOVEMBER					DECEMBER			
WEEK	40	41	42	43	44	45	46	47	48	49	50	51	52
MPCWC	26.4	26.4	26.4	26.4	27.4	28.2	28.2	28.2	28.2	29	29	29	29
75% DR	26.9	26.9	26.9	26.9	24.9	23.3	23.3	23.3	19.9	11.6	11.6	11.6	11.6
75% MCWN	0.5*	0.5*	0.5*	0.5*	2.5	4.9	4.9	4.9	8.3	17.4	17.4	17.4	17.4

MPCWC= Maximum Crop Water Consumption (or Potential Evapotranspiration) when soil is at field capacity (moist).

75% DR = Dependable Rainfall at 75% certainty

75% MCWN= Maximum Crop Water Needs at 75% certainty (Atmospheric Water Balance), when soil is at field capacity (moist).

NOTE: The values in the tables are multiplied by the crop water consumption coefficient/100, for each individual crop according to the crop and its age.

* EXCESS. - No irrigation needed.

When soil is drier than field capacity MPCWC and MCWN are reduced.

WEEKLY CROP WATER NEED TABLE (mm of water)

TABLE 1.2c

CARRINGTON STATION: Altitude 39.63m (130ft)

MONTH	JANUARY				FEBRUARY					MARCH			
WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13
MPCWC	28.2	28.2	28.2	28.2	28.5	28.5	28.5	28.5	32.5	35.6	35.6	35.6	35.8
75% DR	9.3	9.3	9.3	9.3	8.9	8.7	8.7	8.7	7.9	7.3	7.3	7.3	7.4
75% MCWN	18.9	18.9	18.9	18.9	19.6	19.8	19.8	19.8	24.6	28.3	28.3	28.3	28.4

MONTH	APRIL				MAY					JUNE			
WEEK	14	15	16	17	18	19	20	21	22	23	24	25	26
MPCWC	37.3	37.3	37.3	37.3	36.6	36.6	36.6	35.8	35.8	34.8	34.8	34.8	34.8
75% DR	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	9.4	11.6	11.6	11.6	12.6
75% MCWN	29.5	29.5	29.5	29.5	28.8	28.8	28.8	28	26.4	23.2	23.2	23.2	22.2

MONTH	JULY				AUGUST				SEPTEMBER				
WEEK	27	28	29	30	31	32	33	34	35	36	37	38	39
MPCWC	35.1	35.1	35.1	35.1	34.3	34.0	34.0	34.0	32.8	29.7	29.7	29.7	29.7
75% DR	18.5	18.5	18.5	18.5	20.3	21	21	21	22.2	25.3	25.3	25.3	25.3
75% MCWN	16.6	16.6	16.6	16.6	14.0	13.0	13.0	13	10.6	4.4	4.4	4.4	4.4

MONTH	OCTOBER				NOVEMBER					DECEMBER			
WEEK	40	41	42	43	44	45	46	47	48	49	50	51	52
MPCWC	26.4	26.4	26.4	26.4	27.4	28.2	28.2	28.2	28.2	29	29	29	29
75% DR	24	24	24	24	22.7	21.7	21.7	21.7	19.7	17.1	17.1	17.1	17.1
75% MCWN	2.4	2.4	2.4	2.4	4.7	6.5	6.5	6.5	8.5	11.9	11.9	11.9	11.9

MPCWC = Maximum Crop Water Consumption (or Potential Evapotranspiration) when soil is at field capacity (moist).
75% DR= Dependable Rainfall at 75% certainty
75% MCWN= Maximum Crop Water Needs at 75% certainty (Atmospheric Water Balance) when soil is at field capacity (moist)

NOTE: The values in the tables are multiplied by the crop water consumption coefficient/100, for each individual crop according to the crop and its age.

* EXCESS. No irrigation needed.

When soil is drier than field capacity MPCWC and MCWN are reduced.

TABLE 1.24

WEEKLY CROP WATER NEED TABLE (mm of water)

CLAYBURY STATION: ALTITUDE: 231.70 m (760 ft.)

MONTH	JANUARY				FEBUARY					MARCH			
WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13
MPCWC	22.1	22.1	22.1	22.1	22.6	22.9	22.9	22.9	25.1	26.7	26.7	26.7	26.9
75% DR	11.2	11.2	11.2	11.2	9.6	8.4	8.4	8.4	6.0	4.3	4.3	4.3	4.2
75% MCWN	10.9	10.9	10.9	10.9	13.0	14.5	14.5	14.5	19.1	22.4	22.4	22.4	22.7

MONTH	APRIL				MAY					JUNE			
WEEK	14	15	16	17	18	19	20	21	22	23	24	25	26
MPCWC	29.0	29.0	29.0	29.0	30.2	30.5	30.5	30.5	30.0	29.0	29.0	29.0	29.0
75% DR	4.1	4.1	4.1	4.1	9.3	10.1	10.1	10.1	10.0	10.0	10.0	10.0	10.6
75% MCWN	24.9	24.9	24.9	24.9	20.9	20.4	20.4	20.4	20.0	19.0	19.0	19.0	18.4

MONTH	JULY				AUGUST				SEPTEMBER				
WEEK	27	28	29	30	31	32	33	34	35	36	37	38	39
MPCWC	29.0	29.0	29	29	28.7	28.7	28.7	28.7	27.4	27.4	27.4	27.4	27.4
75% DR	14.8	14.8	14.8	14.8	20.5	22.8	22.8	22.8	23	23.5	23.5	23.5	23.5
75% MCWN	14.2	14.2	14.2	14.2	8.2	5.9	5.9	5.9	4.4	3.9	3.9	3.9	3.9

MONTH	OCTOBER				NOVEMBER					DECEMBER			
WEEK	40	41	42	43	44	45	46	47	48	49	50	51	52
MPCWC	23.1	23.1	23.1	23.1	23.1	23.1	23.1	23.1	23.5	24.5	24.5	24.5	24.5
75% DR	27.8	27.8	27.8	27.8	24.9	22.8	22.8	22.8	19.6	11.7	11.7	11.7	11.7
75% MCWN	4.7*	4.7*	4.7*	4.7*	1.8*	0.3	0.3	0.3	3.9	12.8	12.8	12.8	12.8

MPCWC: Maximum Crop Water Consumption (or Potential Evapotranspiration), when soil is at field capacity (moist)

75% DR: Dependable Rainfall at 75% certainty

75% MCWN: Maximum Crop Water Needs at 75% certainty (Atmospheric Water Balance) when soil is at field capacity (moist)

NOTE: The values in the tables are multiplied by the crop water consumption coefficient/100, for each individual crop according to the crop and its age.

* EXCESS - No irrigation needed.
When soil is drier than field capacity MPCWC and MCWN are reduced.

TABLE 1.2e

WEEKLY CROP WATER NEED TABLE (mm of water)

HUSBAND'S STATION: 39.63 m (130 ft.)

MONTH	JANUARY					FEBUARY				MARCH			
WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13
MPCWC	28.2	28.2	28.2	28.2	28.2	28.5	28.5	28.5	32.5	35.6	35.6	35.6	35.6
75% DR	7.8	7.8	7.8	7.8	7.4	7.1	7.1	7.1	6.4	5.9	5.9	5.9	5.9
75% MCWN	20.4	20.4	20.4	20.4	20.8	21.4	21.4	21.4	26.1	29.7	29.7	29.7	29.7

MONTH	APRIL				MAY					JUNE			
WEEK	14	15	16	17	18	19	20	21	22	23	24	25	26
MPCWC	37.6	37.6	37.6	37.6	36.8	36.6	36.6	36.6	35.8	34.8	34.8	34.8	34.8
75% DR	6.1	6.1	6.1	6.1	5.9	5.9	5.9	5.9	7.5	9.8	9.8	9.8	10.4
75% MCWN	31.5	31.5	31.5	31.5	30.9	30.7	30.7	30.7	28.3	25.0	25.0	25.0	24.4

MONTH	JULY				AUGUST				SEPTEMBER				
WEEK	27	28	29	30	31	32	33	34	35	36	37	38	39
MPCWC	34.8	34.8	34.8	34.8	34.3	34.0	34.0	34.0	32.8	29.7	29.7	29.7	29.7
75% DR	14.2	14.2	14.2	14.2	21.6	24.5	24.5	24.5	24.3	23.8	23.8	23.8	23.8
75% MCWN	20.6	20.6	20.6	20.6	12.7	9.5	9.5	9.5	8.5	5.9	5.9	5.9	5.9

MONTH	OCTOBER				NOVEMBER					DECEMBER			
WEEK	40	41	42	43	44	45	46	47	48	49	50	51	52
MPCWC	26.2	26.2	26.2	26.2	27.2	28.2	28.2	28.2	28.2	29.0	29.0	29.0	29.0
75% DR	27.4	27.4	27.4	27.4	24.1	21.7	21.7	21.7	19.7	14.8	14.8	14.8	14.8
75% MCWN	1.2 *	1.2 *	1.2 *	1.2 *	3.1	6.5	6.5	6.5	8.5	14.2	14.2	14.2	14.2

MPCWC: Maximum Crop Water Consumption (or Potential Evapotranspiration,) when soil is at field capacity (moist)

75% DR: Dependable Rainfall at 75% certainty.

75% MCWN: Maximum Crop Water Needs at 75% certainty (Atmospheric Water Balance) when soil is at field capacity (moist)

NOTE: The values in the tables are multiplied by the crop water consumption coefficient/100 for each individual crop according to the crop and its age.

* EXCESS - No irrigation needed.
When soil is drier than field capacity MPCWC and MCWN are reduced.

TABLE 1.2f

WEEKLY CROP WATER NEED TABLE (mm of water)

HOPE STATION: ALTITUDE: 18.29 m (60 ft.)

MONTH	JANUARY					FEBUARY				MARCH			
WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13
MPCWC	28.2	28.2	28.2	28.2	28.2	28.5	28.5	28.5	32.5	35.6	35.6	35.6	35.6
75% DR	6.9	6.9	6.9	6.9	7.0	7.1	7.1	7.1	5.6	4.5	4.5	4.5	4.8
75% MCWN	21.3	21.3	21.3	21.3	21.2	21.4	21.4	21.4	26.9	31.1	31.1	31.1	30.8

MONTH	APRIL				MAY					JUNE			
WEEK	14	15	16	17	18	19	20	21	22	23	24	25	26
MPCWC	37.6	37.6	37.6	37.6	36.8	36.6	36.6	36.6	35.8	34.8	34.8	34.8	34.8
75% DR	6.9	6.9	6.9	6.9	6.5	6.4	6.4	6.4	7.9	10	10	9.7	10.6
75% MCWN	30.7	30.7	30.7	30.7	30.3	30.2	30.2	30.2	27.9	24.8	24.8	25.1	24.2

MONTH	JULY				AUGUST				SEPTEMBER				
WEEK	27	28	29	30	31	32	33	34	35	36	37	38	39
MPCWC	34.8	34.8	34.8	34.8	34.3	34	34	34	32.8	29.7	29.7	29.7	29.7
75% DR	14.4	14.4	14.4	14.4	20.6	23.1	23.1	23.1	22.9	22.4	22.4	22.4	22.4
75% MCWN	20.4	20.4	20.4	20.4	13.7	10.9	10.9	10.9	9.9	7.3	7.3	7.3	7.3

MONTH	OCTOBER				NOVEMBER					DECEMBER			
WEEK	40	41	42	43	44	45	46	47	48	49	50	51	52
MPCWC	26.2	26.2	26.2	26.2	27.2	28.2	28.2	28.2	28.2	29	29	29	29
75% DR	27.4	27.4	27.4	27.4	26.2	25.1	25.1	25.1	21.5	12.5	12.5	12.5	12.5
75% MCWN	1.2 *	1.2 *	1.2 *	1.2 *	1.0	3.1	3.1	3.1	6.7	16.5	16.5	16.5	16.5

MPCWC: Maximum Crop Water Consumption (or Potential Evapotranspiration),when soil is at field capacity (moist)

75% DR: Dependable Rainfall at 75% certainty
75% MCWN: Maximum Crop Water Needs at 75% certainty (Atmospheric Water Balance) when soil is at field capacity (moist)

NOTE: The values in the tables are multiplied by the crop water consumption coefficient/100, for each individual crop according to the crop and its age.

* EXCESS - No irrigation needed.
When soil is drier than field capacity MPCWC and MCWN are reduced.

WEEKLY CROP WATER NEED TABLE (mm of water)

TABLE 1.2g

JORDAN STATION: Altitude 118.90 m (390ft)

MONTH	JANUARY					FEBRUARY				MARCH			
WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13
MPCWC	24.2	24.2	24.2	24.2	24.5	24.7	24.7	24.7	27.2	29	29	29	29.5
75% DR	10.3	10.3	10.3	10.3	9.7	9.3	9.3	9.3	8.0	7.1	7.1	7.1	7.2
75% MCWN	13.9	13.9	13.9	13.9	14.8	15.4	15.4	15.4	19.2	21.9	21.9	21.9	22.3

MONTH	APRIL				MAY					JUNE			
WEEK	14	15	16	17	18	19	20	21	22	23	24	25	26
MPCWC	33	33	33	33	32.5	32.5	32.5	32.5	31.8	30.7	30.7	30.7	30.7
75% DR	7.5	7.5	7.5	7.5	8.8	9.1	9.1	9.1	9.6	10.3	10.3	10.3	11.6
75% MCWN	25.5	25.5	25.5	25.5	23.7	23.4	23.4	23.4	22.2	20.4	20.4	20.4	19.1

MONTH	JULY				AUGUST				SEPTEMBER				
WEEK	27	28	29	30	31	32	33	34	35	36	37	38	39
MPCWC	31	31	31	31	30.7	30.7	30.7	30.7	29.5	26.2	26.2	26.2	26.2
75% DR	19.6	19.6	19.6	19.6	22.1	23.1	23.1	23.1	24.1	26.7	26.7	26.7	26.7
75% MCWN	11.4	11.4	11.4	11.4	8.6	7.6	7.6	7.6	5.4	0.5 *	0.5 *	0.5 *	0.5 *

MONTH	OCTOBER				NOVEMBER					DECEMBER			
WEEK	40	41	42	43	44	45	46	47	48	49	50	51	52
MPCWC	25.9	25.9	25.9	25.9	25.4	25.1	25.1	25.1	25.2	25.4	25.4	25.4	25.4
75% DR	30.7	30.7	30.7	30.7	25.4	21.2	21.2	21.2	19.8	16.5	16.5	16.5	16.5
75% MCWN	4.8 *	4.8 *	4.8 *	4.8 *	0	3.9	3.9	3.9	5.4	8.9	8.9	8.9	8.9

MPCWC=Maximum Crop Water Consumption (or Potential Evapotranspiration) when soil is at field capacity (moist)

75% DR= Dependable Rainfall at 75% certainty

75% MCWN= Maximum Crop Water Needs at 75% certainty (Atmospheric Water Balance) when soil is at field capacity (moist)

NOTE: The values in the tables are multiplied by the crop water consumption coefficient/100, for each individual crop according to the crop and its age.

* EXCESS:- No irrigation needed.

When soil is drier than field capacity MPCWC and MCWN are reduced.

WEEKLY CROP WATER NEED TABLE (mm of water)

TABLE 1.2h

LANCASTER STATION ALTITUDE: 121.9m (400ft)

MONTH	JANUARY				FEBRUARY				MARCH				
WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13
MPCWC	24.1	24.1	24.1	24.1	24.5	24.7	24.7	24.7	27.1	28.9	28.9	28.9	29.5
75% DR	12.4	12.4	12.4	12.4	12.1	11.9	11.9	11.9	9.5	7.6	7.6	7.6	7.8
75% MCWN	11.7	11.7	11.7	11.7	12.4	12.8	12.8	12.8	17.6	21.3	21.3	21.3	21.7

MONTH	APRIL				MAY					JUNE			
WEEK	14	15	16	17	18	19	20	21	22	23	24	25	26
MPCWC	33	33	33	33	32.5	32.5	32.5	32.5	31.7	30.7	30.7	30.7	30.7
75% DR	8.5	8.5	8.5	8.5	9.4	9.6	9.6	9.6	11.0	13.0	13.0	13.0	14.1
75% MCWN	24.5	24.5	24.5	24.5	23.1	22.9	22.9	22.9	20.7	17.7	17.7	17.7	16.6

MONTH	JULY				AUGUST				SEPTEMBER				
WEEK	27	28	29	30	31	32	33	34	35	36	37	38	39
MPCWC	31	31	31	31	30.7	30.7	30.7	30.7	29.5	26.2	26.2	26.2	26.2
75% DR	21.1	21.1	21.1	21.1	27.9	30.6	30.6	30.6	31.5	34	34	34	34
75% MCWN	9.9	9.9	9.9	9.9	2.8	0.1	0.1	0.1	2.0 *	7.8 *	7.8 *	7.8 *	7.8 *

MONTH	OCTOBER				NOVEMBER					DECEMBER			
WEEK	40	41	42	43	44	45	46	47	48	49	50	51	52
MPCWC	25.9	25.9	25.9	25.9	27.4	25.1	25.1	25.1	25.4	25.4	25.4	25.4	25.4
75% DR	33	33	33	33	28.2	24.9	24.9	24.9	23.3	19.4	19.4	19.4	19.4
75% MCWN	7.1 *	7.1 *	7.1 *	7.1 *	0.8 *	0.2	0.2	0.2	2.1	6	6	6	6

MPCWC = Maximum Crop Water Consumption (or Potential Evapotranspiration) when soil is at field capacity (moist)

75% DR= Dependable Rainfall at 75% certainty

75% MCWN= Maximum Crop Water Needs at 75% certainty (Atmospheric Water Balance) when soil is at field capacity (moist)

NOTE: The values in the tables are multiplied by the crop water consumption coefficient/100, for each individual crop according to the crop and its age.

* EXCESS. No irrigation is needed.

When soil is drier than field capacity MPCWC and MCWN are reduced.

[illegible]

TABLE 1.2i

WEEKLY CROP WATER NEED TABLE(mm of water)

SPENCER'S STATION:ALTITUDE: 54.88m (180 ft.)

MONTH	JANUARY				FEBUARY					MARCH			
WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13
MPCWC	28.2	28.2	28.2	28.2	28.5	28.5	28.5	28.5	33.0	35.6	35.6	35.6	35.6
75% DR	8.1	8.1	8.1	8.1	7.6	7.4	7.4	7.4	6.6	5.8	5.8	5.8	5.6
75% MCWN	20.1	20.1	20.1	20.1	20.9	21.1	21.1	21.1	26.4	29.8	29.8	29.8	30.0

MONTH	APRIL				MAY					JUNE			
WEEK	14	15	16	17	18	19	20	21	22	23	24	25	26
MPCWC	37.3	37.3	37.3	37.3	36.6	36.6	36.6	36.6	35.8	34.8	34.8	34.8	34.8
75% DR	4.6	4.6	4.6	4.6	6.1	6.4	6.4	6.4	7.1	8.4	8.4	8.4	9.1
75% MCWN	32.7	32.7	32.7	32.7	30.5	30.2	30.2	30.2	28.7	26.4	26.4	26.4	25.7

MONTH	JULY				AUGUST				SEPTEMBER				
WEEK	27	28	29	30	31	32	33	34	35	36	37	38	39
MPCWC	35.1	35.1	35.1	35.1	34.3	34.0	34.0	34.0	32.8	29.7	29.7	29.7	29.7
75% DR	14.2	14.2	14.2	14.2	18.0	19.6	19.6	19.6	19.3	19.1	19.1	19.1	19.1
75% MCWN	20.9	20.9	20.9	20.9	16.3	14.4	14.4	14.4	13.5	10.6	10.6	10.6	10.6

MONTH	OCTOBER				NOVEMBER					DECEMBER			
WEEK	40	41	42	43	44	45	46	47	48	49	50	51	52
MPCWC	26.4	26.4	26.4	26.4	27.4	28.2	28.2	28.2	28.2	29	29	29	29
75% DR	22.1	22.1	22.1	22.1	19.6	17.5	17.5	17.5	15.8	11.4	11.4	11.4	11.4
75% MCWN	4.3	4.3	4.3	4.3	7.8	10.7	10.7	10.7	12.4	17.6	17.6	17.6	17.6

MPCWC= Maximum Crop Water Consumption (or Potential Evapotranspiration),when soil is at field capacity (moist)

75% DR= Dependable Rainfall at 75% certainty

75% MCWN= Maximum Crop Water Needs at 75% certainty (Atmospheric Water Balance)when soil is at field capacity (moist)

NOTE: The values in the tables are multiplied by the crop water consumption coefficient/100, for each individual crop according to the crop and its age.

* EXCESS - No irrigation needed

When soil is drier than field capacity MPCWC and MCWN are reduced.

TABLE 1.3

MOISTURE STORAGE CAPACITY OF SOME BARBADIAN SOILS

SOIL NO.	ASSOCIATION	STORAGE % FOR GROWTH UP TO SURVIVAL (Permanent wilting)	STORAGE % FOR ACTIVE GROWTH (Up to 1 bar suction)
34	Black	21.4	16.9
30	Black	18.7	14.6
21	St. George's Valley	17.9	13.9
13	St. Philip's Plain	21.8	17.3
46	Grey Brown	15.0	11.3
46	Grey Brown	12.5	9.3
41/40	Grey Brown	12.9	9.3
50	Yellow Brown	10.5	7.8
60	Red Brown	9.2	6.7

NOTE: Storage expressed as % of soil depth in use.

EXAMPLE: If a plant has most of its roots in 15cm of Soil No. 34, then the water storage in the root zone for active growth is 15 cm x $\frac{16.9}{100}$ = 2.53 cm of water or 25.3mm.

NOTE ON SOURCE: Data of J.C. Hudson. See Reference No. 4. In order to convert moisture storage to % of soil depth in use, the following soil monolith heights were kindly supplied to the author by J.C. Hudson by personal communication. Soil 34, 79.5cm; Soil 30, 78cm; Soil 21, 81.5cm; Soil 13, 69cm; Soil 46, 60cm; Soil 41/40, 73cm; Soil 50,77cm; and Soil 60, 80.5cm.

1 bar suction storage was estimated from the formula $W = b_o u^{b_1}$, where W = soil moisture %, b_o = constant, b_1 = constant and u = soil water suction in bars. (See Reference No. 1)

CHAPTER 2

(section A)

WATER SUPPLY IN BARBADOS

by

David Croney [1/]

In Barbados water occurs naturally both as underground (groundwater) and surface water. Another often used "source" is the public supply; its use is subject to the control of the Waterworks Department (W.W.D).

Groundwater occurs mainly on the coral side of the island, and surface water as run-off in the Scotland District. Springs are a type of surface flow which occurs when groundwater emerges at the surface. Spring flows are mainly confined to the Scotland District, (e.g Newcastle, Codrington College), except for a few sources (e.g Three Houses, Fortescue) on the coral side. River flows in the Scotland District are very unreliable, occuring as "flash" floods after heavy rains, while often drying up in the dry season.

Groundwater is a much more reliable source. The coral rock in general is like a sponge, highly receptive to rainfall, most of which (some 80 to 90%) either refills the soil reservoir and is evapotranspired,(*) with any excess going as Recharge to augment groundwater. Run-off is a relatively rare event (only some ½ inch yearly on the average), being more common on the steeper West Coast than in the Constitution river catchment.

The modes of occurence of groundwater are shown in Fig. 2.1, an East/West section of the island, including the Scotland District (vertical dimen-

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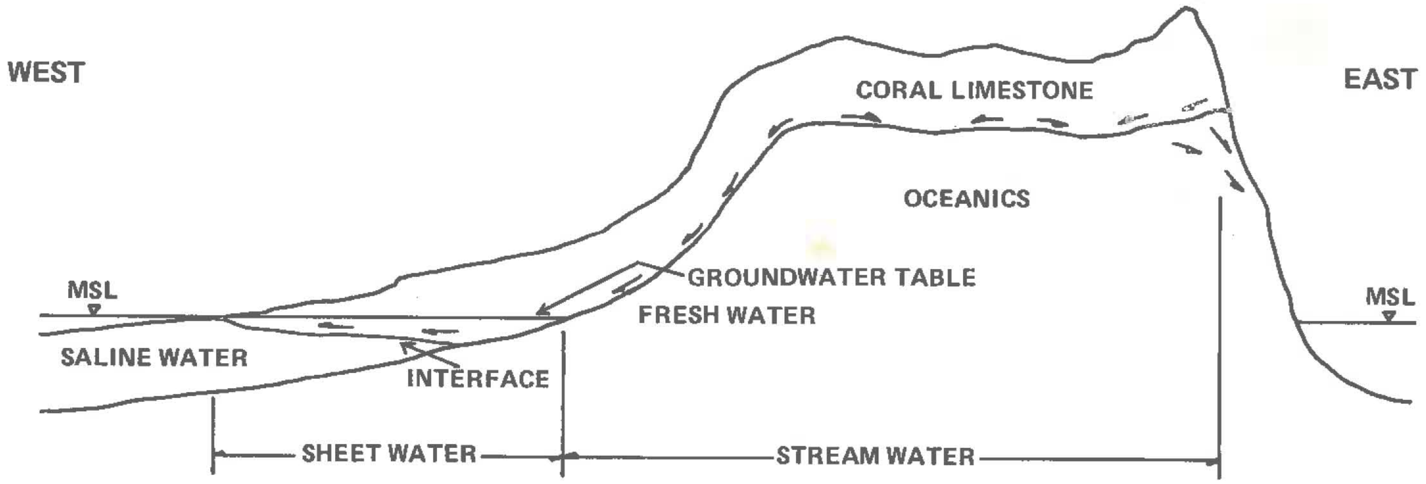
1/ Head of Land and Water Use Unit, Ministry of Agriculture, Food and Consumer Affairs.

(*) Evaporation from the soil surface plus transpiration by plants.

sions are exaggerated). The permeable coral limestone overlies the impermeable oceanic rock, except in the Scotland District, where both the coral and most of the oceanic rock have been removed by geological erosion, laying bare the softer clays, silts and sands of the Scotland rocks. From the West coast, the coral limestone rises from the sea in a series of steep escarpments to the highest points bordering the Scotland District, which falls off steeply to the sea. Rain falling as shown on the coral side infiltrates and goes to groundwater chiefly via bare rock outcrops, natural depressions (dolines) with/out man made suck wells, and, after run-off, in the gullies (dry river courses) themselves, this latter especially at higher elevations. As shown depressions in the oceanics can give rise to perched water tables, which overflow when filled and add to the general flow Westward to the sea. This flow, which occurs above mean sea level (m.s.l), is termed stream water, since flow is mainly in solution channels (formed by the action of the weak carbonic-acid-carbon dioxide dissolved in water - on the limestone rock) e.g. Bowmanston, Harrison's Caves. Unfortunately the topography of the base of the coral (i.e. the surface of the oceanic rock) does not always conform with surface topography. As a result, locating these underground streams can be a difficult exercise, often involving considerable costly exploratory drilling. The greatest benefit in locating sizeable quantities of water in this zone accrues to the W.W.D., since a high elevation source reduces power changes for pumping.

Where the oceanic coral contact is at m.s.l, the stream water, (plus recharge from rain incident on the area itself), "backs up" in the connected

FIGURE 2.1



SIMPLIFIED HYDROGEOLOGICAL
CROSS SECTION OF BARBADOS

pores of the coral rock to form a "lake" of fresh water "floating" on the heavier sea water, and separated by a "contact surface" as shown in Fig.2.2. This zone is termed sheet water. The diagram gives an oversimplification of reality; in actual fact the contact surface has some thickness, being a "mixing zone" where an equilibrium is reached between incoming sea water and outgoing fresh water (ignoring inputs of domestic-sewage-water, and extraction for domestic and agricultural use). Salt content[*] of this layer can vary from 200 parts per million (p.p.m) chloride ion concentration (Cl^-) - the maximum desirable for potable purposes - to 600 ppm Cl^-, at which level (as a "rule of thumb") salt sensitive crops and some soils may be affected - to pure sea water (about 19,000 + ppm Cl^-). This "mixing zone" thickens near the sea (due mainly to tidal effects), and the depth of fresh water also lessens. On the other hand in some areas (notably the St. George Valley) the "toe" of the interface does not extend the full distance of the zone inland - see Fig. 2.3. In addition, the surface of the sheet water, which is at atmospheric (phreatic) pressure slopes gently upwards from the coastline inland, so that at a distance of 1 to 2km from the sea its elevation may be of the order of ¾ to 1½m. The extent of the stream/sheet water zones and the Scotland District are shown in Fig. 2.4.

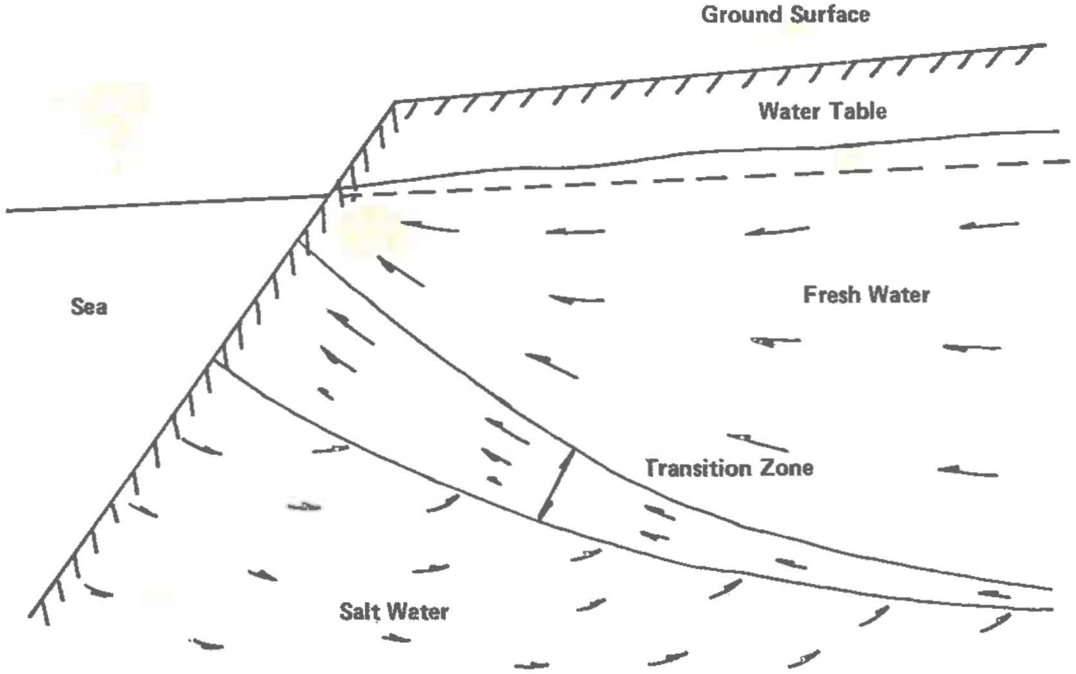
(*) To date sea water is the major contaminant, although possible pollution by agro-chemicals (especially pesticides), domestic detergents and heavy metals from industry and even oil spills must be carefully monitored. Protection form domestic sewage effluent is provided for by the creation of "safety" zones around public potable supply wells.

Presently abstraction of groundwater is under the control of the Water Board, which grants permission for a limited (renewable) period for abstraction at a given rate, usually in Imperial gallons per minute (Imp. g.p.m.). Permission must first be obtained to a) dig a well b) alter an existing well c) abstract water from a well. Application forms are available from either the Secretary of the Water Board (W.W.D, Pine, St. Michael) or the Extension or Irrigation Services of the Ministry of Agriculture. With regard to surface water, however, legislation is less clear, probably because this has not been a major source of supply. Legislation is now being enacted to regularise the use of water, and to generally make water for irrigation more widely available. Co-operatives can obtain from Government an incentive grant of 75% of the total costs of installing an irrigation system, and bonafide individual farmers 50% for total costs up to a maximum of $12,000 (i.e $6,000).

Twelve (12) million Imp. g.p.d have been allocated to agriculture, while only some 4.3 million Imp.g.p.d are being used. Most of the reserves lie in the Eastern half of the St. George Valley. The major factor limiting full use is the availability of markets for the produce in excess of local needs.

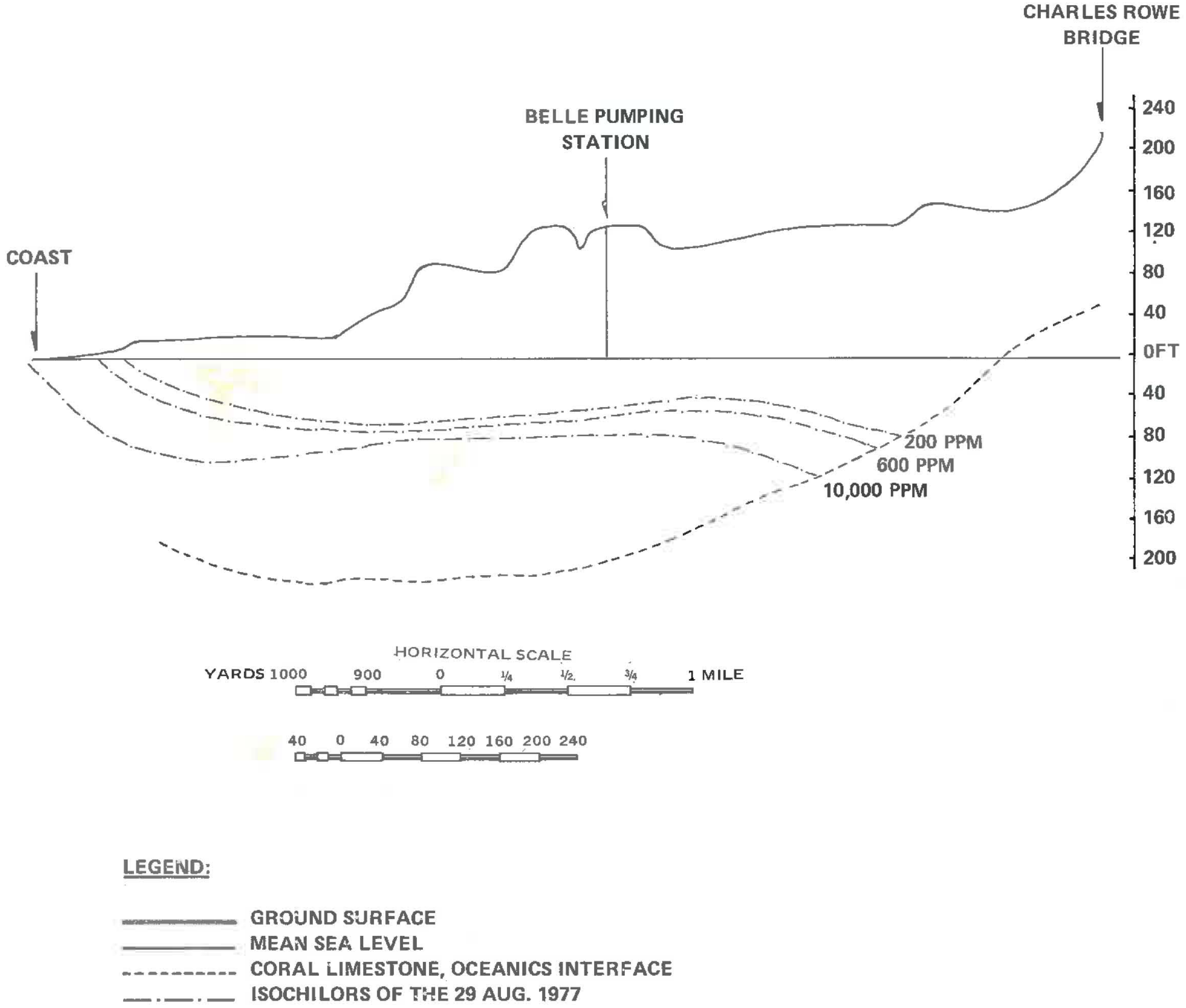
Reliability of supply is an important factor in irrigation planning as noted in Chapter 1. A one in four year rainfall below average is a generally accepted risk. The effect of low rainfall of this frequency would be evident in diminished flows in surface water (Scotland District), run-off (coral area), and to a lesser extent in spring flows. The groundwater reserves will, however

FIGURE 2.2



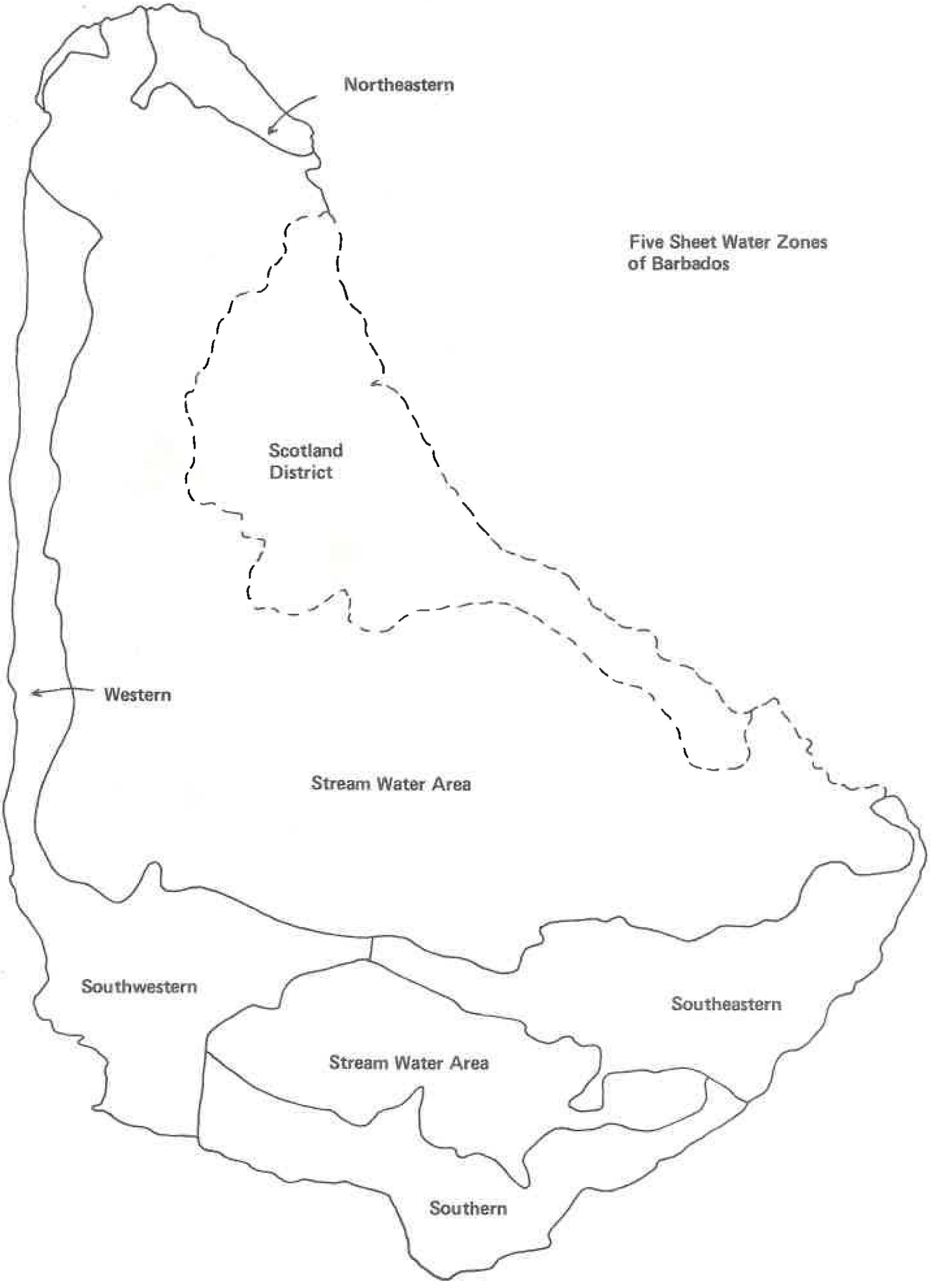
Vertical Cross-Section Illustrating the Flow System where a Hydrodynamic Balance Exists between Fresh and Saline Waters in a Coastal Aquifer.

FIGURE 2.3



CROSS SECTIONAL PROFILE OF CORAL FORMATION BETWEEN CHARLES ROWE BRIDGE AND NEW ORLEANS THROUGH THE BELLE PUMPING STATION

FIGURE 2.4


Northeastern
Five Sheet Water Zones of Barbados
Scotland District
Western
Stream Water Area
Southwestern
Southeastern
Stream Water Area
Southern

yield their required quota.

The quantity of water which can be allocated in any given area depends on its mode of occurence and conflicting uses. In the Scotland District silt free flows are limited to spring flows, and reliability is low. In practice water is collected in ponds set-off from,but near to the water course. Filter inlets are laid in the river bed at the required elevation up-stream, and silt free water piped into the ponds. Only those ponds in sandy areas suffer excessive leakage, and must be sealed, (in practice by a compacted clay layer). A bulldozer uses the excavated soil (down to near ground water table) inside the dam itself to build the banks; usually a final depth of some 15 feet, and storage of 2 to 3 million Imperial gallons are achieved.

On the coral side, little storage is practiced, the groundwater acting as a huge reservoir tapped by hand dug wells to water table. In the stream water zone, location of flow is the major problem, and in addition wells generally need to be quite deep. Water may be abstracted at virtually any rate without fear of contamination, the only limit being the supplying capacity of the source. In the sheetwater zone, two major zones can be recognised (see Fig. 2.1) depending on whether the salt/brackish water does/not underly the fresh water. In the latter case, abstraction rates can be high; the only limitation being the permeability of the rock, and the total exhaustion of the reserves of the acquifer (water bearing rocks) itself. In the former case, however, (fresh water underlain by salt water) especially as one approaches the coast, the danger of salt water intrusion limits production from a single well, even if adits, i.e. horizontal tunnels at water level, area dug. Here the danger is contamination at a particular point, ie. well, although the yield capacity of the area itself is not exceeded. The coral rock varies greatly (up to 20 X*) in its permeability, which may also vary in the horizontal and vertical plane. In practice, therefore, water must be pumped as slowly as possible, preferably, under the worst conditions, (ie. generally near the coast, where the fresh water lens is thin, and consequently the brackish water nearer the surface), on a 24 hour basis. This will require provision for overnight or weekend storage of pumped water and generally provision of a separate pump to draw from storage and operate (ie. provide pressure needed by) the sprinklers. For overall development of these critical areas, a large number of wells pumped at a slow rate are more effective than a small number pumped at a high rate. Drawdown ie. the extent to which the groundwater level in the well basis is lowered, should not exceed a couple of inches (since for every foot of drawdown, the contact surface rises some forty (40)

(*) A measure of the relative ease with which it will transmit, and therefore yield, water.

ft. to a new equilibrium position).

Wells increase in yield with time as fine particles blocking pores are "sucked in", and solution widens existing and creates new channels. It is often necessary to clean a well shortly after it is dug to get rid of these fine particles, which when pumped give the appearance of a pseudo "salt crust" on the soil surface. In practice the farmer can only increase the effectiveness of his supply by increasing his irrigation efficiency, and, on the national scale, by keeping his suck well drainage system clean. The burning of canes, and the practise of furrowing (especially up and downhill) rather than cane holes, has increased soil erosion. Poorly designed/operated systems also tend to choke up sucks with inwashed soil particles.

The crux of the water supply problem in Barbados is the seasonal and **erratic** pattern of rainfall. Storage of wet season flows, either of surface or groundwater, requires costly measures - either surface storage, or recycling of groundwater. Without these measures, it is impossible to use the total annual yield of a given area. In practice a 50% recovery is high under Barbados conditions.

CHAPTER 2

(section B)

PUMPS AND POWER UNITS

by

Kenneth Kuhr

Irrigation means moving water. To move water requires a pump and a power source. First, look at pumps.

I- Pumps

A. Types of pumping plants

There are three kinds of pump commonly used in Barbados: Centrifugal, Submersible and Piston.

1. A centrifugal pump is generally used to pump from reservoirs, tanks or ponds. It can be powered by either an electric motor or by an internal combustion engine. The pump can be run efficiently over a range of speeds. A centrifugal pump can suck water, but it must be primed, and it must be located near the water surface. One should try to locate the pump less than five meters above the water. See figure 2.5.

Priming a pump is accomplished by filling the suction pipe and the pump with water. A foot valve will keep the water from flowing back into the reservoir, thus eliminating the need for priming at every start-up. As a foot-valve wears out, it must be replaced or repaired, or some means of completely filling the suction side must be provided. A foot-valve is not needed with a self-priming pump or with a diaphragm pump primer. In all cases, a strainer should be used in the suction line to prevent debris from entering the system.

2. A submersible pump is already fitted with an electric motor designed to run at one speed. The pump and motor are both submerged, hanging by the riser pipe from support beams across the top of the well. This pump is most often used in deep wells. See figure 2.6. A control cable runs from the motor up to a switch-box. The switch-box contains a starter and protective devices to prevent motor damage. Submersible pumps are generally fitted with a switch to cut-off the motor if the water level in the well drops to within about 15cm of the intake.

3. Piston pumps are used with windmills and with diesel engines. They are not commonly installed at present in Barbados. The output is relatively low, generally about five g.p.m. Any such system must have a pressure release valve and an air chamber to dampen pulsations on diesel-powered installations. Often, a well that has produced satisfactorily with a piston pump will not produce the large flowrate required for efficient irrigation.

There are other types of pumping plants, but they are not commonly used in Barbados.

B. Pump Selection

To select a pump, one must know: Total Dynamic Head, Flowrate and Efficiency.

1. Total Dynamic Head (TDH) consists of the height (both suction and delivery) of the water must be pumped, the pressure at which the system will operate, and the friction loss in the pipelines and fittings. TDH is generally expressed in units of length (feet or meters). To convert pressure, in psi, to feet, multiply by 2.31. Divide to go the other way.

FIGURE 2.5

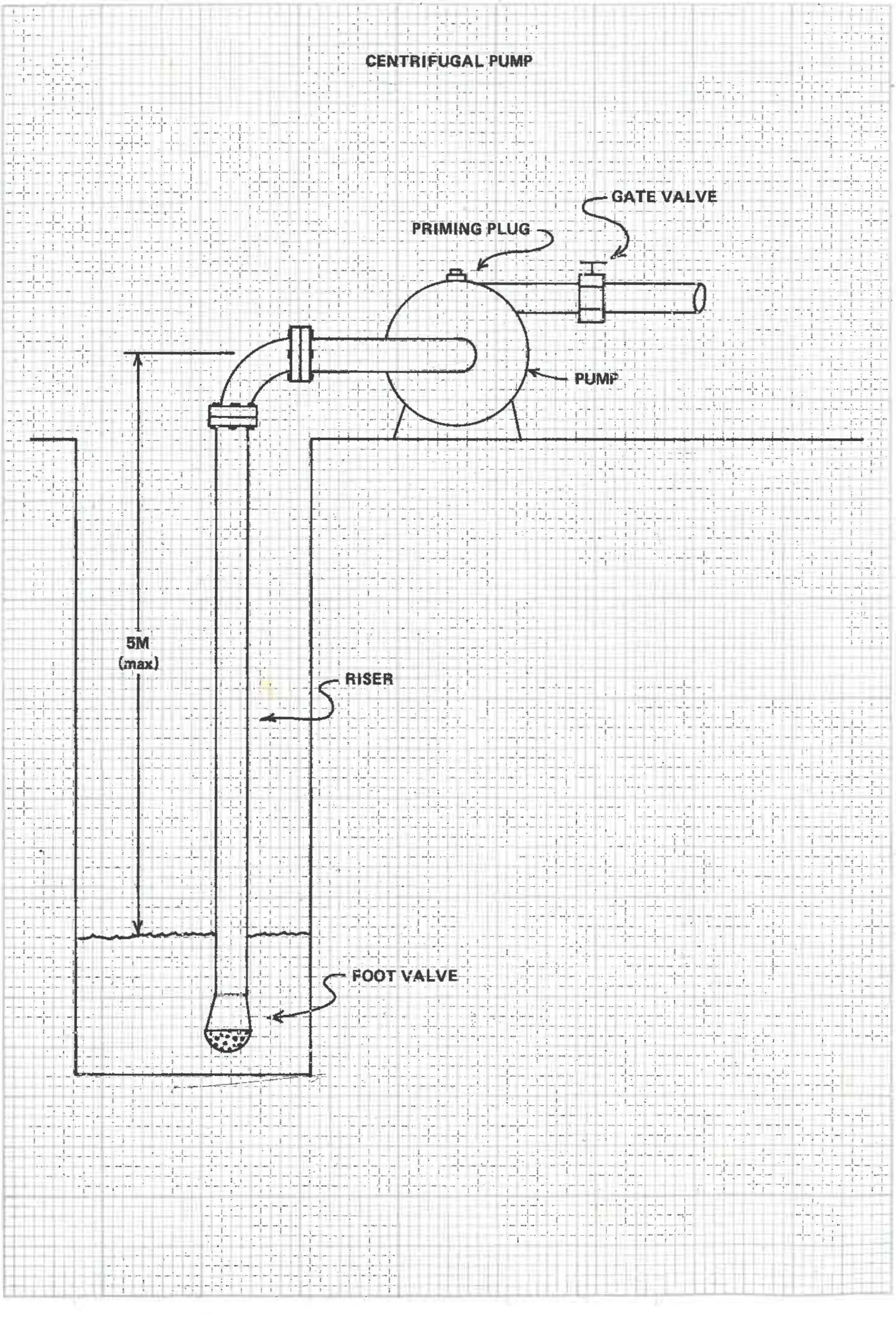
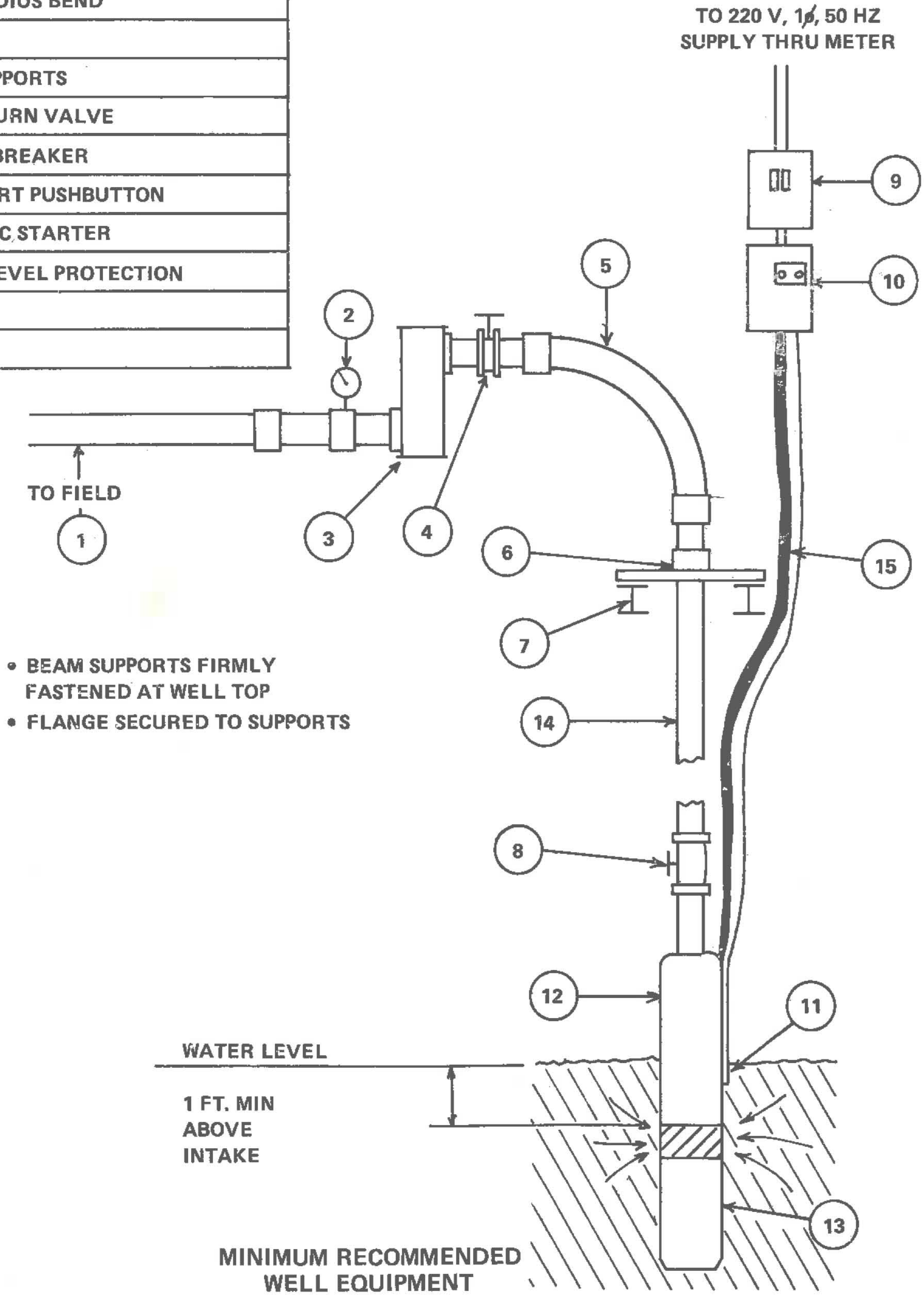

CENTRIFUGAL PUMP
GATE VALVE
PRIMING PLUG
PUMP
5M
(max)
RISER
FOOT VALVE

FIGURE 2.6

NUM.	ITEM	NUM.	ITEM
1	1.5 IN PVC PIPE	14	RISER PIPE
2	PRESSURE GAGE	15	ELECTRIC CABLE
3	FILTER		
4	GATE VALVE		
5	LONG RADIUS BEND		
6	FLANGE		
7	BEAM SUPPORTS		
8	NON-RETURN VALVE		
9	CIRCUIT BREAKER		
10	STOP-START PUSHBUTTON		
	MAGNETIC STARTER		
11	WATER LEVEL PROTECTION		
12	PUMP		
13	MOTOR		



- BEAM SUPPORTS FIRMLY FASTENED AT WELL TOP
- FLANGE SECURED TO SUPPORTS

MINIMUM RECOMMENDED
WELL EQUIPMENT

Eg:

40 psi x 2.31 ft/psi = 92.4ft

2. Flowrate

The speed with which water passes a given point in an open or closed conduit is called the velocity (V), and it is expressed in units such as feet per second, meters per second, miles per hour, etc. The velocity times the cross-sectional area of the flowing stream of water (A) is the rate of flow or rate of discharge (Q).

Eg:

$$Q = A \times V$$

Common units of rate flow are cubic feet per second, U.S. gallons per minute, Imperial gallons per minute, litre per second and cubic meter per hour.

3. Efficiency is very important. A pump operating at 40% efficiency will cost 1.5 times as much as a pump operating at 60% efficiency. A prospective buyer should insist that a dealer find an efficient pump for his system. Seventy five per cent is an extremely good efficiency; forty per cent is poor.

A dealer who knows what he is doing will use pump charts. See figure 2.7. Each pump has a unique curve that describes the performance of that pump at a particular speed. This curve shows the performance, efficiency, and horsepower requirement of a pump supplied by Pumping Systems Limited. If one wanted a submersible pump to supply 50 g.p.m against a 200 ft TDH, this pump would work. It would require a 5 hp motor and is 68% efficient. This particular pump comes with a 6 hp motor as noted at the upper right. To maintain this efficiency, the pump should always be run at, or near 50 g.p.m and 200 ft TDH.

In buying a second-hand pump, one must be sure that it meets the requirements of the system. Ask the previous owner for any papers he may have concerning the pump performance. Then seek advice on the purchase of the pump from a pump supplier or from the Irrigation Unit of the Ministry of Agriculture.

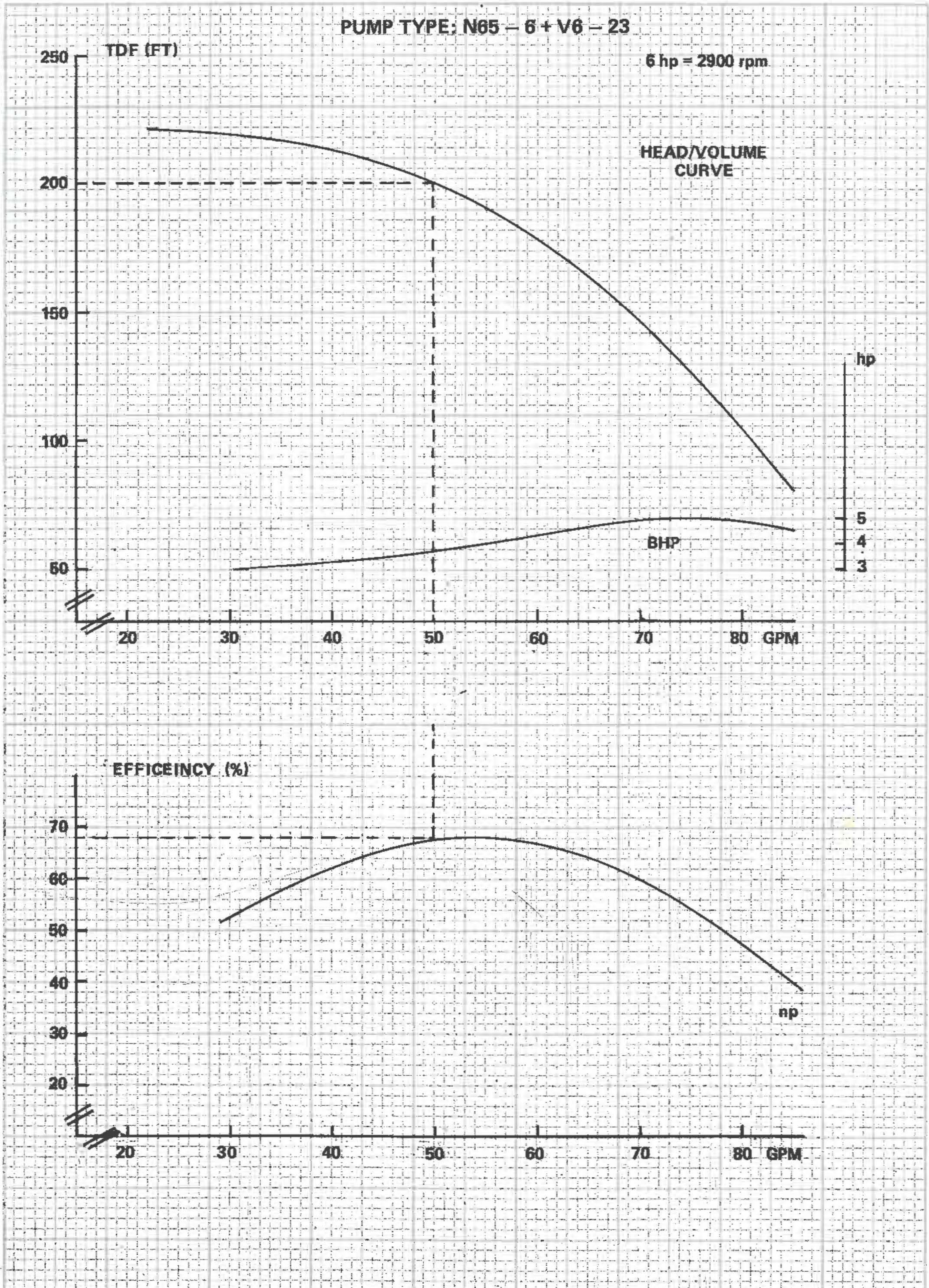
Pumps wear out. As they wear, efficiency, TDH, and flowrate will decrease; therefore, it is often advisable to buy equipment that is just slightly oversized.

C. Pump Operation

Danger of overloading a centrifugal or submersible pumping unit comes when operating at a low TDH and high flowrate. This happens when the system is open or when just starting the system with all valves open. To avoid overloads of this nature, close all valves before turning on the system. Then open the valves slowly, starting near the pump and working toward the sprinkler lateral. Do not leave a pump running with all valves closed for long periods of time. Some pumps have plastic impellers which might warp from the heat produced in such situations.

Pumps should be chosen carefully, operated efficiently, and maintained properly to assure long life, good performance, and maximum returns.

FIGURE 2.7


PUMP TYPE: N65 – 6 + V6 – 23
TDF (FT)
6 hp = 2900 rpm
250
200
150
100
50
HEAD/VOLUME CURVE
hp
5
4
3
BHP
20
30
40
50
60
70
80
GPM
EFFICEINCY (%)
70
60
50
40
30
20
np
20
30
40
50
60
70
80
GPM

II- Power Units

The two main sources of power for pumping are internal combustion engines and electric motors. Which of the two is best depends on individual installation conditions. Among the most important factors are the following:

- Horsepower required and hours of operation. Electricity rates depend upon the size of the motor and the number of hours of operation. A large motor that is not used often is generally uneconomical. This is important to a farmer who irrigates only in the dry season.
- Cost of fuel. Even here, comparisons are difficult because fuel prices change rapidly.
- Initial cost, lifetime, and maintenance. A large electric motor has a life of approximately 50,000 hr. A diesel engine will last about 30,000 hr. Maintenance on a diesel (lubrication, attendance and repairs) is about 15 times as much as on an electric motor. The initial cost is often affected by whether the item is in stock or not. Generally, in-stock items are cheaper than items that must be ordered.
- Pump requirements. Deep well or surface, portability.
- Availability of power. To run power lines and hang transformers for a well installation may prove extremely costly. Check with Barbados Light and Power for a cost estimate.

- Varying system requirements. Internal combustion engines operate efficiently over a range of speeds. Motors operate at a single speed.

- Power failures, fuel shortages, and downtime for repair.

All these factors should be considered before choosing a power unit.

In choosing a power source, one must ensure that the pump and the power unit are matched properly. Size, type, and other factors must be considered, just as in the selection of what kind of power source one will use.

To determine approximately what size of power unit you will need, use the basic horsepower formula:

$$hp = \frac{Igpm \times TDH}{3300 \times eff}$$

where: hp = horsepower into pump
Igpm = Imperial gallons per minute
TDH = Total Dynamic Head
eff = pump efficiency (found on pump curve, see figure 2.7).

If you use a diesel engine, multiply the above horsepower by 1.2 to get the minimum required engine size. An electric motor should be big enough to supply the calculated horsepower requirement. As stated previously, the pump curve should have a curve to show what horsepower is used by the pump.

Electric motors are commonly used in Barbados. Any such motor over 5hp must be 3-phase with reduced voltage starting. Any 3-phase installation is billed on a special rate, not the domestic rate. The various rates are shown in Chapter 4 Appendix 2. Motors generally **maintain** their efficiency throughout their lifetime. 3-phase motors are more efficient than single-phase motors. Any motor should be run at its design speed and load (run the recommended number of sprinklers) to maintain maximum efficiency.

The term "submersible pump" refers to a pump and motor combination in which the motor is mounted below the pump. The pump is a vertical turbine centrifugal pump and is made up of one or more stages. The entire assembly is suspended by the riser pipe, the intake being placed at least 30cm below the water surface. (see figure 2.6).

Diesel engines are most often used to pump from surface storage tanks or ponds. They are also used on booster pumps and to power a few deep-well turbine pumps. They are started by an electric motor or by hand crank. Fuel consumption is approximately 15hp-hr per gal (US). This means that for every 15hp, an engine will use one gallon of fuel per hour. This rule, along with the price of diesel fuel, would allow estimation of cost of fuel for planning purposes and calculation of pumping plant efficiency. Larger engines should be fitted with protection devices to turn them off if oil pressure drops or if temperature gets too high. All engines should be protected from weather. Maintenance procedures as outlined by the dealer should be meticulously followed. All these tips will help ensure long life of a diesel engine.

Along with engines, some mention should be made of PTO pumps. These pumps attach to the PTO shaft of a tractor. They are relatively cheap and are easy to transport; however, they have the disadvantage of tying up a tractor during irrigation.

If you are considering installing irrigation or already have it in operation, try to use the points presented to operate efficiently, save fuel, and save money.

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2. SCHWAB, G.O. et al. Soil and Water Conservation Engineering, John Wiley, New York. 1966.

CHAPTER 3

(section A)

DESIGN OF SPRINKLER IRRIGATION SYSTEMS

by

David Croney (*)

Introduction

The objective of sprinkler (and in fact all) irrigation design is to provide, as economically and efficiently as possible, especially with regard to water use and power requirements, water of adequate quantity and quality, when and where required, bearing in mind the constraints under which the farmer must function; and the need to at least conserve, if not improve, the fertility of the soil.

There is no "ideal" design for all situations - each must be treated as unique and tailored to satisfy the needs of the farmer. Within certain constraints, there is a range of designs possible; in general selection involves a "trade-off" between capital and operating costs (labour and power); least labour intensive systems requiring the highest capital investment and power requirements, and vice versa.

Design is always based on the sustained peak demand over a period without any rainfall, this quantity being determined by statistical analysis of rainfall and evapotranspiration data; which give an economically acceptable "risk" factor (see chapter 1). Soil conditions, and especially the farmers cropping cycle, play an important role in determining this demand. A

(*) Head of Land and Water Use Unit, Ministry of Agriculture,Food and Consumer Affairs.

specialist farmer, growing one crop (presumably for an assured market) will require a higher peak design than if he staggered his production, requiring higher power and larger pipe sizes. On the other hand, his efficiency of water application[1] will be higher and labour costs probably lower. In addition, a single crop is generally simple to manage. The farmer who staggers his planting and/or grows a variety of crops, in order to safeguard himself against market fluctuations, will have lesser peak demands and pipe sizes requirements, but also lesser efficiency of water application, and generally higher labour costs; however the management will be more complicated.

The design of an irrigation system can be broken down into steps or a "flow chart", as is illustrated in Figure 3.1.

Resource Inventory

1. Map of Design Area

This should include:-

a) The boundary of the area to be irrigated, with apportionment to one or various crops and rotation programmes.

b) Contours every 1,5m or 5ft if the land is not level. If these are unavailable the 20ft contours of the 1:10,000 Barbados topographic map must be used, and a few "spot" heights with a visual appreciation of slope being made by the designer,

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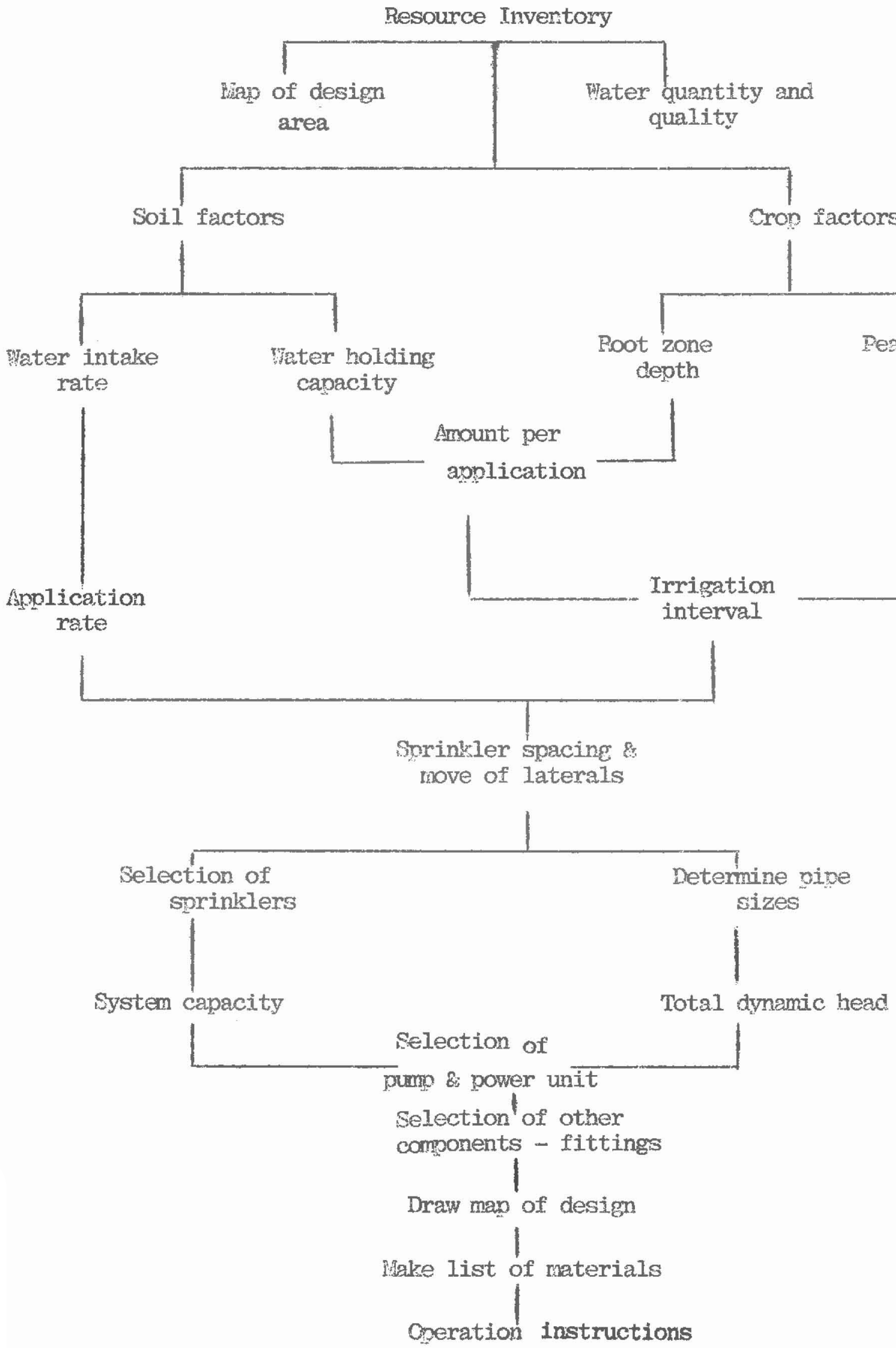
[1] The overall efficiency of water application is measured by the ratio of the amount transpired by the crop to the amount abstracted from the source.

FIGURE 3.1

FLOW CHART FOR DESIGN OF SPRINKLER TYPE SYSTEMS



c) Drainage features such as sucks.

d) Source of water and power to drive pumps.

e) Any obstructions to the laying/or moving of pipes.

f) Direction of prevailing wind.

2. Water quality and quantity

a) Permission has to be obtained from the Water Board or Water Authority to abstract water at a maximum rate of 50 Imp. gallons per minute (50 i.g.p.m).

b) The quality of water should be such as to pose no problems from salinity, and hence no leaching of soil is required. Leaching is a process whereby a calculated excess of water is added to the soil, after cropping and at predetermined intervals, and which serves to "flush down" any build-up of excess harmful salts. In Barbados generally there is no need for leaching, both because the water is of a good quality, and heavy rainfall in the wet season effectively leaches the soil.

Crop Factors

1) Root zone depth (see chapter 1)

2) Peak use rate.

This largely a function of climate, and is the water evapotranspired by a crop at maximum usage rate, when foliage completely covers the soil surface, and factors favouring evaporation are highest, i.e high temperature, bright sunshine, low humidity and high wind.

Because of the smoothing out effect of soil as a storehouse for water, and the possibility of rain in the interim, we generally use the maximum average over 2-3 weeks, using (as noted in chapter 1) the one in four year drought as an acceptable level of risk.

Operational requirements are automatically covered by design, and the farmer should be involved in this, in order to ensure that it meets his operational needs, which are often less than and should never exceed peak design rate.

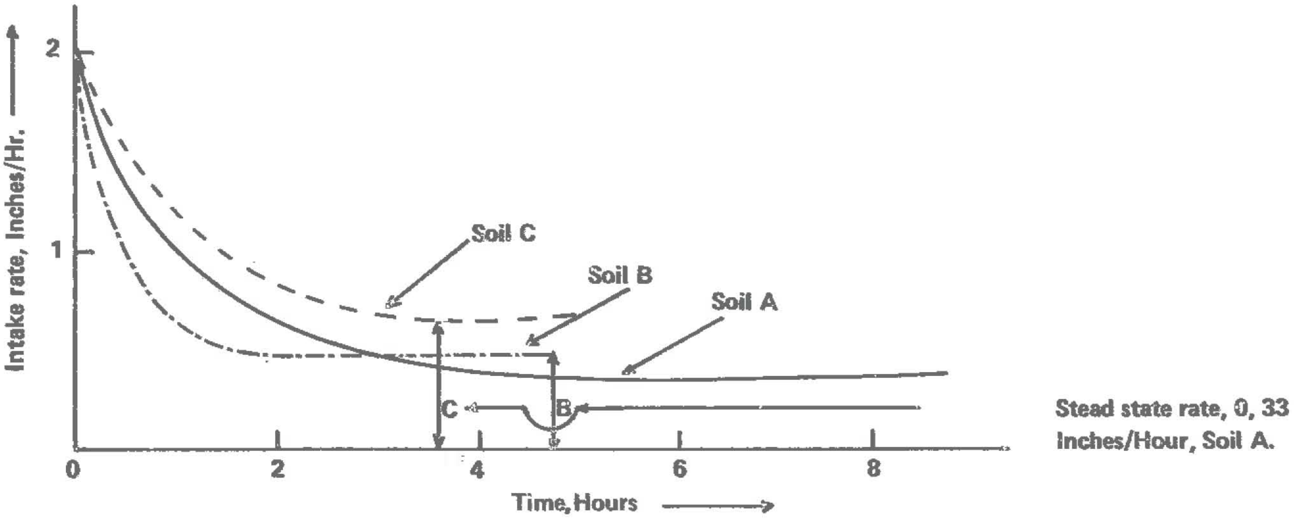
In a low rainfall area such as Spencers, a design for vegetables would be of the order of 0.20 inches per day (i.p.d). Using 0.20 ipd, and a soil such as No. 46 with a moisture storage of 1.5 inches of water for 16.4 inches of soil, we must replenish 1.5 inches of water every 1.5/0.2 = 7.5 days, and for safety and convenience it is assumed to be every 6 days. (see page 1.9).

Soil Factors

1) Water intake rate

A good average figure is in practice very difficult to determine as it varies both during the course of a given irrigation, and throughout the growing season, as soil structure changes-due to tillage, compaction during cultivation operations, harvesting, etc. It depends on both the infiltration and the percolation rate, ie. the rate at which water enters, and the rate at which it passes through the soil. See Figure 3.2 and Table 3.1.

FIGURE 3.2
VARIATION OF WATER INTAKE RATE WITH TIME



From the Figure 3.2 it can be seen that for Soil A intake rate is very rapid (2 inches/hour) at the start of irrigation, but drops rapidly at first and then more slowly until a steady rate of some 1/3 inches/hour is reached after about 6 to 8 hours. This intake rate must be <u>reduced</u> for sloping land; reference to Figure 3.3. and Table 3.2 shows that for a slope of 6%, the precipitation rate is reduced by 20%; so the water intake rate for that slope is:

$$\text{WIR } (6\%) = 0.33 \text{ inch/hour } \times \frac{80}{100} = 0.26 \text{ inch/hour}$$

$$\text{WIR } (6\%) = 0.26 \text{ inch/hour}$$

2) Available Water Holding Capacity (AWHC)

Based on soil type, the AWHC can be broadly estimated for different soils, but ideally determinations should be made by field measurements - some of these are given in chapter 1, where the AWHC has been called "Storage in the soil, of water that plants can use." Table 1.3 shows this moisture storage capacity of some Barbadian soils.

3) Amount of Application

Now it is required that 1.5 in reach and infiltrate the soil; we must therefore consider another factor termed <u>IRRIGATION</u> <u>EFFICIENCY</u>. This is often defined as:-

$$\text{IRRIGATION EFFICEINCY} = \frac{\text{QUANTITY OF WATER ABSORBED IN REQUIRED DEPTH OF WETTING}}{\text{TOTAL QUANTITY OF WATER APPLIED}}$$

The total quantity of water applied, is generally taken as from sprinkler nozzles; however if the system is not well maintained high losses can occur due to leaks along the delivery mains, especially at joints where seals are worn. See Table 3.3, for typical figures on irrigation efficiency.

Sprinkler spacing and moving of laterals

These two design criteria are especially important under our windy conditions. In order to avoid erosion, it is recommended to cultivate, or run our beds, as close to the contour as practical - here from north-west to south-west (See Figure 3.3) with surface drainage as shown, and also giving a slope of about 6% which is not excessive. Since in Barbados the wind is predominantly from one direction we adopt a rectangular sprinkler setting pattern, with the greatest distance in the direction of the wind. High wind velocity is the most important single factor affecting uniformity of application and efficiency.

The former is determined in practice by a standard measuring technique, which gives a coefficient of uniformity. For sprinklers, this should be of the order of 80% plus. In Barbados, especially where high capacity and pressure "rain guns" are used on vegetables, we have found that, in order to apply say one inch, parts of the area wetted will receive two inches. On slopes this causes erosion. The latter, should ideally be determined by field tests i.e under differing wind and water conditions. Table 3.4 shows typical coefficients of uniformity (C_U) for wind speeds of 2 and 9 miles per hour.

"Cropwinds" often exceed 10 m.p.h during the day, and in some locations eg. Grantley Adams Airport, do not drop to less than three quarters to two-thirds of daytime velocity during night hours. Test results indicate a spacing of 20 feet or 30 feet at these velocities. This requires a large number of sprinklers, and it is often difficult to find a suitable type (even with a single nozzle) to meet with the reduced delivery rate required.

Layout of the sprinkler system

At this stage we must use the scale diagram for planning various trial layouts i.e. position of mains, submains, laterals, pipe diameters, number and capacity of sprinklers, and maximum length of lateral line. For even distribution, ideally each sprinkler on the lateral should receive water at the same pressure. This is impractical. We compromise with what is commonly termed the "20% rule" i.e a 20% variation in pressure between the first and the last (distal) sprinkler on the lateral line will give a variation in water distribution of 10%, acceptable for practical purposes. As a given volume of water flows along a sprinkler line, pressure is reduced due to friction loss. However as each sprinkler abstracts its quota, this volume (and hence friction loss) is reduced. In addition, we must take into account the differences in elevation: a) between first and last sprinklers, assuming a generally even slope in between, and b) of the heights of sprinkler risers. In Figure 3.3 is shown a layout of mains and submains. In order that laterals run (as far as practical) across the slope, three possible layouts may be considered.

Slopes of lateral directions are the same for (1), (2) and (3). Layout (1) uses minimum mainline but the laterals will run uphill, not the best layout for achieving even distribution. Layout (3) requires greatest length of mainline, but down slope setting works to achieve greater uniformity of pressure distribution. Layout (2) is intermediate; however the line running across the field may hinder mechanisation unless adequately buried. Let us select layout (3) as optimal. In figure 3.4 there is a model for an irrigation layout for a 5 acres farm. Now, there are some calculations to be made in order to complete the design.

System Capacity

1) Duration of the setting ("Set")

At a required gross amount of application of 2.14 inches, a minimum time for one "set" i.e lateral line (s) in one position in order to "top up" soil storage, is:-

$$\text{"Set"} = \frac{\text{Peak use amount of application}}{\text{Application rate}}$$

$$\text{"Set"} = \frac{2.14 \text{ inch}}{0.26 \text{ inch/hour}}$$

$$\text{"Set"} = 8.56 \text{ hours or approx. } 8\tfrac{1}{2} \text{ hours}$$

2) Area covered by a setting ("Set")

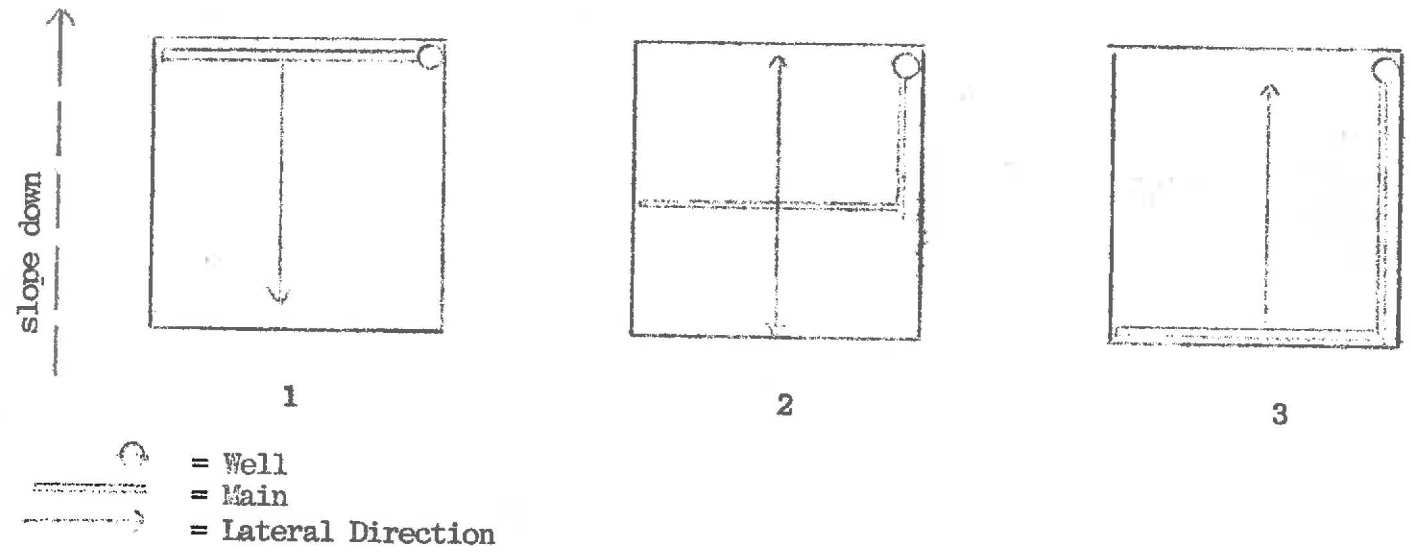
In our model (see Figure 3.4), the number of take-off hydrant valves (twelve) strongly suggests a six day cycle of one sprinkler line moved once per day (i.e two "Sets"/day). Each sprinkler line setting should cover approximately $\frac{\text{5 acres}}{\text{12 positions}} = 0.42$ acres.

3) Well capacity and duration of setting.

It is necessary to ensure that the well capacity of fifty Imp.g.p.m. is not exceeded, using the Formula.

FIGURE 3.3

LAYOUT OF MAINS AND SUBMAINS ACCORDING WITH
THE PREVAILING SLOPE



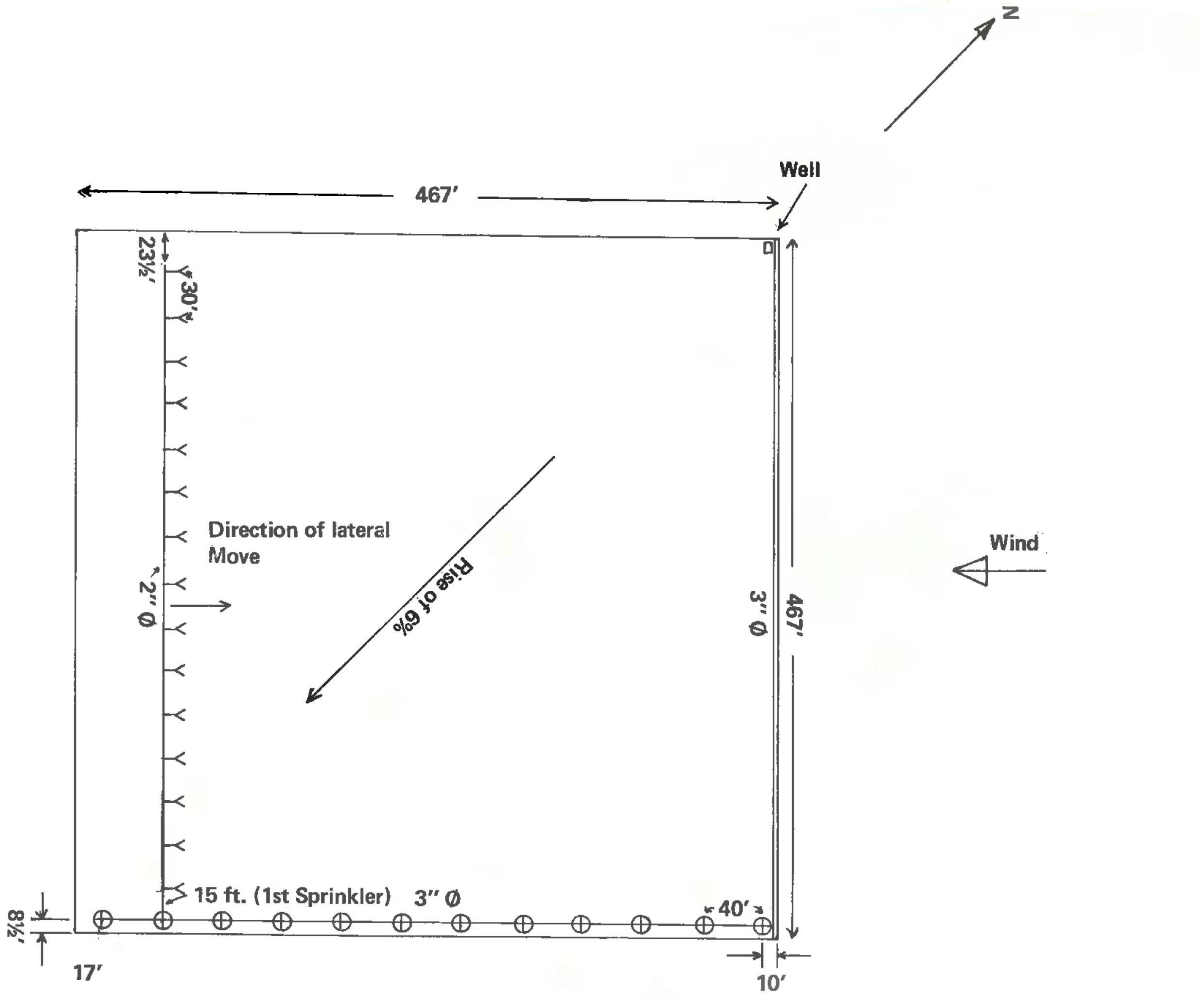


Fig 3.4 MODEL FOR AN IRRIGATION LAYOUT FOR A 5 ACRES FARM

SCALE 1″ = 100′

$$G\ total = \frac{22{,}610 \times I \times A}{H \times D \times 60} \quad \text{Imp. g.p.m.}$$

Where 22,610 = Imp. g. in one acre inch

I = inches of water to be applied

A = total acreage to be covered

H = hours of operation/day

D = days required to cover

G_{total} = well capacity, Imp.g.p.m.

60 = 60 mins/hour

From the above equation we get:

$$H = \frac{22{,}610 \times 2.14 \times 5}{50 \times 6 \times 60} = 13.44 \text{ hours/day}$$

This is the limiting factor, thus the 8½hours duration of setting calculated above is impractical unless we consider providing overnight surface storage. (See section: Resource inventory 2(a)).

4) Flow rate per sprinkler

The number of hours of operation per day is 13.44. This gives a precipitation rate of:-

$$\frac{\text{Amount to be applied}}{\text{Time available}} = \frac{2.14 \text{ in}}{13.44 \text{ hrs}} = 0.16 \text{ in/hr.}$$

Gallons/sprinkler required in this case would be:-

$$G_s = \frac{P \times A}{115.6}$$

Where P = precipitation rate, in/hr.

G_s = gallons per sprinkler (Imp. g. p. m.)

A = spacing of sprinklers (30' <u>on</u> lateral x 40' <u>between</u> laterals)

115.6 = a constant to give answer in units required i.e Imp. g. p. m.

$$G_s = \frac{0.16 \times 30 \times 40}{115.6} = 1.66 \text{ Imp. g. p. m.}$$

5) Number of sprinklers

The number of sprinklers is determined by the ratio between total gallons per minute required and the flow capacity of each sprinkler.

$$\text{No. sprinklers} = \frac{G_t}{G_s}$$

$$\text{No. sprinklers} = \frac{50 \text{ Imp. g. p. m.}}{1.66 \text{ Imp.g.p.m}}$$

$$\text{No. sprinklers} = 30$$

This seems an excessive number for so small an area; the yield of the well could be a limiting factor in management; and we are constrained to an approximate nine hour set by limitation of infiltration rate. We could store 45,000 Imp.g by pumping (24-9) = 15 hours with a pump rate of 50 Imp.g.p.m. A smaller electrical submersible can be operated, pressuring the sprinklers with a well head power unit.

On the other hand we must recognize that 13.44 hours is at peak capacity, and if our planting is so arranged as to dampen peak demand, an approximately two-thirds capacity (8.56h/13.44h) should meet our needs.

Sprinkler Selection

Considering now sprinkler selection, and using as an example "Rainbird"1/ (see Figure 3.5) it seems as if we can only obtain the required diameter (80ft) with a rate of some 2.5 Imp.g.p.m.

If the design rate proves too high as evidenced when observation in the field shows run-off is occuring on sloping ground, it may be possible to change the nozzles on our sprinklers to a smaller diameter to give a suitable rate. Rate reduction is however limited by the capacity of the smaller jet to operate the rotating (spring action) mechanism of the sprinkler. Another option is to operate on the "hop along" system, i.e use alternate sprinklers, operating (some systems have provision for valve closure when the riser with its sprinkler is removed) alternate sprinkler positions on the sprinkler lines.

Our major problem is the close spacing required by high winds; since this is the most effective method of increasing application uniformity (see Table 3.6).

Manufacturers give little other information on increasing uniformity -

"the sprinkler manufacturers should be able to help field irrigation engineers select the sprinkler to be used for high uniformity."

1/ Mention of any particular product does not necessarily imply an endorsement of that product by Ministry of Agriculture, Food and Consumer Affairs or Inter-American Institute of Agricultural Sciences (IICA).

Nozzle design and pressure combinations are important and too high/low pressure should be avoided. Low angle sprinklers are available, but are generally used in orchard (under tree) applications, and their diameter of throw is usually inadequate. Windbreaks, preferably of a crop with some value (e.g. sorghum) can significantly lessen the effect of wind if planted at sufficiently close intervals.

Lengthier sets (i.e time a lateral is in one position) combined with alternate sprinkler positions tend to increase application efficiency. The effect of "offsetting", is controversial. This is a practice whereby at every other irrigation cycle the lateral lines are placed mid-way between their previous position. U.S experience is that it is of value, but Israeli experience is that much depends on the variation in direction and velocity of the wind.

Suppose we select the 20 EJH Rainbird, 45 p.s.i (nozzle $\frac{1}{8}$"). throw 81ft, 2.59 i.g.p.m. (3.11 US. g.p.m.). See Figure 3.5. We now have some definite figures to work on:-

1) Calculation of precipitation rate per sprinkler:-

$$\text{Precipitation rate } G_s = \frac{\text{i.g.p.m.} \times 115.6}{A} = \frac{2.59 \times 115.6}{30 \times 40} = 0.25 \text{ i.p.h}$$

2) Calculation of precipitation total.

Using two sets/day of 8.56 hours,

$$G_t = \frac{22{,}610 \times 2.14 \text{ ins} \times 5 \text{ ac.}}{(8.56 \times 2) \times 6 \times 60} = 39.3 \text{ Imp.g.p.m.}$$

as a check from the above information.

15 sprinklers at 2.59 i.g.p.m. = 2.59 x 15 = 38.9 i.g.p.m.

It now remains to be seen what diameter of lateral will satisfy the "20% rule". A mathematical formula can be used; but usually calculations are made using special irrigation slide rules or nomographs. These provide a graphical solution to the mathematical equation involved. (See Appendix 1 or nomograph No.1).

Basically we determine the pressure loss in the lateral for its required length and total flow rate, and modify this by a factor which depends on the number of sprinklers. Using the nomograph given, we get:-

At 3.11 US. g.p.m. (1½" diamter lateral)
(2" diamter lateral)
15 sprinklers, 30ft on lateral, pressure loss is 16 p.s.i.
4,6 p.s.i.

Pressure gain (since lateral runs downhill) is $\frac{19ft}{2.31(ft\ to\ p.s.i)}$ = 8.2 p.s.i(pounds/square)

20% of 45 p.s.i = 9 p.s.i. ie. lateral loss/gain must not exceed 9 p.s.i. ie.

For 1½" lateral, 16 - 8.2 = +7.8 p.s.i, a pressure LOSS
For 2" lateral, 4.6- 8.2 = -3.6 p.s.i, a pressure GAIN.

Both 1½ inch and 2 inch lateral diameters are therefore acceptable. Riser height here is negligible (1½ft).

Pressure loss in the mains

Now we must consider pressure loss in the mains (and submains). As a general rule this should not exceed 10 p.s.i. Using nomograph 2 inch in appendix

No. 2 and from the calculation already done:

39.3 Imp.g.p.m. approximately equals 50 US. g.p.m, then it is recommended to use the Scobey Friction Factor of 0.4 for portable aluminium and couplers. This is one of various friction loss formulas used. Each one is assigned to a particular pipe material. There is also an experimentally determined factor - coefficient to be applied.

Length pipe = (467 x 2) + 100 = 1034ft say 1000ft.

From nomograph. 2.3 inch main gives pressure loss 0.33 p.s.i/100ft=
33 p.s.i. /1000 which is acceptable.
2 inch main gives pressure loss 2.8 p.s.i/100ft=
28 p.s.i/1000 which is not acceptable.

then, 3 inch is satisfactory and it may be worth while to check out a 2½ inch one.

Horsepower (HP) requirements and TDH

Now to obtain Horsepower (H.P) required:-

$$\text{Water horsepower} = \frac{\text{Imp.g.p.m. x total dynamic head (t.d.h.)(ft)}}{3{,}300}$$

1) Where tdh is the total dynamic head and 3300 is a constant to give correct units, tdh comprises:-

a) sprinkler operating (nozzle) pressure =
45 p.s.i. x 2.31 (convert to feet head) = 104 ft
b) Lift (water surface to well head) = 100 ft
c) Delivery head (well head to highest point of land) = 40 ft
d) Main line losses 3,8 p.s.i. x 2.31 = 9 ft
e) 75% of lateral loss 1/ = $(-3.6 \times 2.31) \times \frac{75}{100}$ = - 6 ft
TOTAL 247 ft

1/Note here, by using 2 inch lateral, we have a gain in pressure from first to last sprinkler - mathematically expressed as a negative (i.e reducing total) head.

Total B/fwd = 247 ft

Allow 10% for losses (through valves, bends,

fittings, risers, sprinklers, etc.) say 25ft = 25 ft

t.d.h =(a + b + c + d + e) = t.d.h = 272 ft

2) Efficiency

Now there are various energy losses in conversion of energy,(electrical, petroleum products etc.) via motor to and by the pump itself. For an electrical submersible pump we use an overall figure of 70%.

$$\text{i.e actual H.P. required} = \frac{\text{Water H.P}}{\text{Efficiency}}$$

$$= \frac{40 \times 272}{3300 \times (70/100)} = 4.7 \text{ H.P}$$

In practice we would select a 5 H.P. electric motor and for a gasoline motor (water cooled), multiply by 1.45 and a diesel motor (water cooled). multiply by 1.25.

It must be stressed that the design above is <u>not</u> the <u>only</u> solution to this particular problem. Certain factors cannot (or at least not easily) be changed eg. wind velocity, soil characteristics i.e. slope, infiltration rate, profile characteristics, depth and well capacity, while others are more amenable to our control e.g hours of operation/day (with storage provided to prevent excess demands on well yield), horse power and size of mains/laterals, degree of automation (labour saving and monitoring devices) or number of lateral lines provided.

CHAPTER 3

(section B)

SPRINKLER SELECTION AND MAINTENANCE

by

K. Kuhr, Peace Corp Volunteer

I <u>Choosing Sprinkler Irrigation Equipment</u>

A. Suppliers

The three main suppliers of irrigation equipment in Barbados are Central Foundry, Plantrac and Pumping Systems Limited. Various estates and individual farmers have used equipment for sale. If you want to buy or sell used equipment, ask around.

The Irrigation Unit, M.A.F.C.A and the Barbados Agricultural Society might be of help. You can also order directly from companies in other countries. Equipment comes in duty-free. If the company already has an agent here, they will either instruct you to work through their agent, or deal with you directly and still send a commission to their agent. The biggest disadvantage of importing is that you will not get the service local agents may provide. The service includes design, installation, and operating instructions. Also, if the system you import breaks down you may have difficulty getting a local agent to fix it.

Whenever dealing with local agents you should demand good service, ask questions about how to maintain and operate the system.

B. Designing

The Irrigation Unit can design a system for you. They will give you a list of components required for an efficient system. They will also explain how such a system should be operated. Even if you allow the dealer to design for you, you should still get the design checked by the Irrigation Unit. This is especially important if you wish to apply for the Incentive Grant later on.

One good rule about design - the less labor you want to expend, the more equipment you will require and the higher will be your initial cost. Try to look ahead in planning, because the Incentive Grant applies to first purchase only. The grant covers 50% of the first $12,000 spent, if the system gains the approval of the Irrigation Unit.

For example, if your system costs $10,000 for the bare essentials, and if a system a bit easier to operate would cost $12,000, you should seriously consider buying the more expensive system. That extra $2,000 would really only be costing $1,000 (with the 50% grant). Also, equipment prices are rising and what costs $40 today may be $48 tomorrow and $60 in two years.

C. Differences in equipment

Laterals and mainlines:

1) Check for ease of coupling and uncoupling.
2) The male end should be rolled inward to avoid damaging the seal. Burred edges should be filed down. (see Figure 3.6)
3) The Female end should be securely attached to the pipe. One that is press-fitted is preferred. Make sure that replacement seals are readily available.

4) Risers:
   - a) Consider the height of the crop and the depth of the furrow in determining riser height.
   - b) Galvanized risers are much sturdy than aluminium risers.
   - c) To hinder workers from moving the lateral by grabbing the riser, keep it short as possible.

5) Riser supports:
   - a) Aluminium plate will cause the riser to lean if not placed properly. The advantage of a plate is that it is permanently attached to the lateral. See Figure 3.7a
   - b) Wire struts are more trouble to handle and are easily lost if not painted brightly. They do not require even ground for placement. See Figure 3.7b
   - c) Sticks may be tied to the riser and firmly planted in the ground.

6) Sprinklers should be checked for ease of tension spring adjustment and disassembly. Two nozzles will give a higher percipitation rate than one. Low pressure sprinklers are available from Israel.

7) Take-off hydrant and valves, should be checked to make sure that the springs and other moving parts are not located in the water stream. They easily and quickly corrode. Figure 3.8

Not all systems will have all the advantages. Just look carefully to know what you are buying. Try to figure what precaution will be required to overcome disadvantages.

D. In-stock equipment

Sometimes a dealer will sell equipment that may be oversized. One reason for this is that his in-stock large size may be cheaper than the smaller size which must be ordered. This is due to the rapidly rising cost of equipment. Once again, do not hesitate to ask the dealer questions.

II Maintenance and Repairs

A. Maintenance

The idea of maintenance is to get the maximum life from your equipment. The pipelines, sprinklers and pumping plant should be kept in good shape.

Pipe must be treated gently. Do not force them in any situation. Give them good support along their entire length. Don't rest the pipes on rocks, nor walk on them. Replace badly worn or weathered seals. Make sure hooks are secure and properly located. Store pipes on racks, in the shade, away from concrete and fertilizer.

As for sprinklers, do not oil them. The bushings are designed for water lubrication. If the sprinkler does not turn, check the pressure to make sure it is within operating range. Then, push the sprinkler head down and release a few times to clear any dirt particles. If that does not work, try tightening the arm spring. Lastly, the sprinkler may require a whole new set of bushings which should be available from the dealer in kit form. Before you purchase such a kit, compare the cost of a new sprinkler.

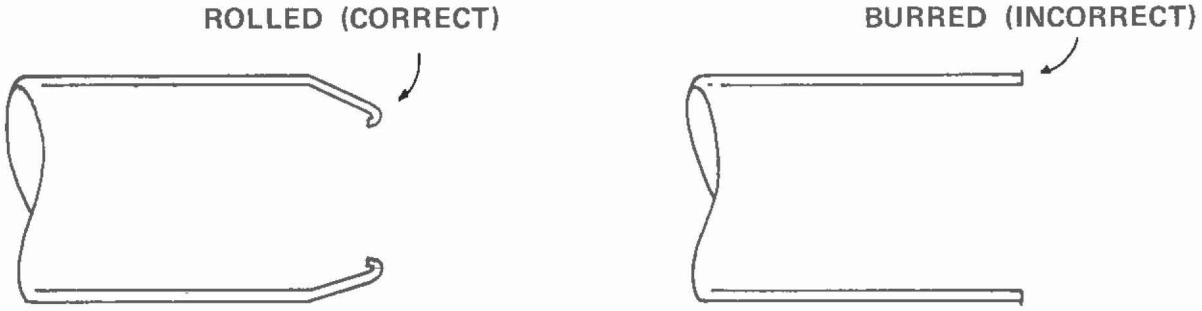


Fig 3.6 LATERAL ENDS-MALE

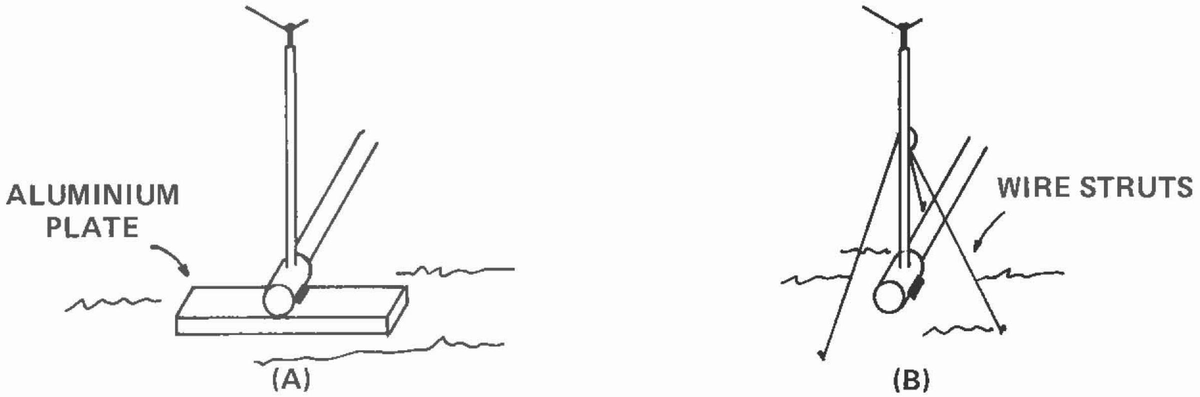


Fig. 3.7 RISER SUPPORTS

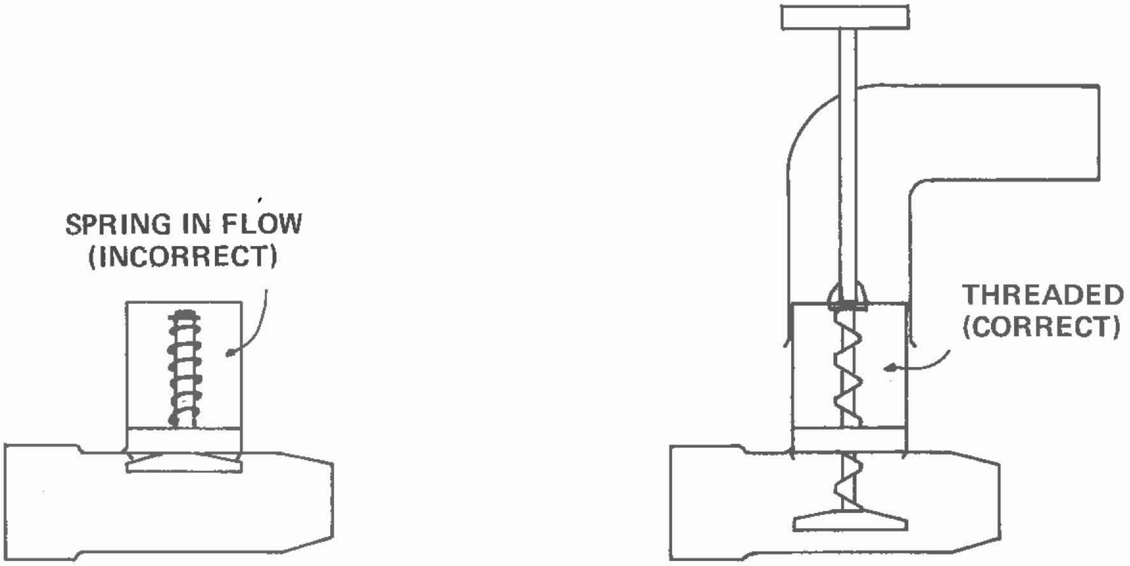


Fig. 3.8 TAKE-OFF HYDRANT AND VALVE

Electrical pumping plants require little maintenance; however, motors and electrical starters should be kept clean and free from dust and grass build-up. Diesel engines should be maintained according to dealer specifications.

B. Repair

Sprinkler and aluminium pipes can be repaired. As previously stated, reconditioning kits are sometimes available for sprinklers. As for pipes and fittings, there are welders in Barbados who can weld aluminium.

An alternate method of repairing holes in pipes is by using fibreglass. The materials can be purchased from Caribbean Fibreglass, Black Rock, St. Michael. A brief outline of the procedure is as follows:-

1) Clean the pipe with a wire brush around the hole and three inches to either side of the hole, all the way around the pipe.
2) Fill in large dent with automotive body filler or with successive layers of glass matt soaked in resin.
3) Coat the area to be covered, with resin that has been mixed with hardener.
4) Wrap the pipe twice with fibreglass matt that you have soaked with resin. Keep the wrap tight.
5) Let harden.

For more instructions, contact the Irrigation Unit, Ministry of Agriculture Food and Consumer Affairs, or ask the person at "Caribbean Fibreglass" who sells the material.

If you have to cut a pipe, be sure to file the edges to prevent the burred edge from cutting the seal.

CHAPTER 3

(section C)

AN INTRODUCTION TO TRICKLE IRRIGATION

by

Nathan Bailey, Peace Corp Volunteer, U.S.

"Trickle" or "Drip Irrigation" is named so because in this method of irrigation water slowly trickles or drips from small emitters directly onto the soil surrounding the plants' roots. The rate of water flowing from the emitter varies between 2 and 10 liters per hour (.44 and 2.2 gallons per hour (Imp)), which is extremely slow especially when compared to the range for the nozzle in sprinkler irrigation (which is 180-12,000 lph or 40-2500 gph).

But there are many distinct advantages of trickle irrigation: 1) there can be water application efficiencies approaching 100% and water savings of 30-50% over other methods of irrigation because with trickle water is only applied to the local area containing the plants' roots; 2) there is no unnecessary wetting of foilage and subsequently there is a great decrease in the incidence of insect, disease, and fungus attack; 3) it can be adapted to uneven terrain; 4) it produces constant low-tension moisture conditions in the soil; 5) it can be placed under plastic mulches; 6) its local water application inhibits weed growth; 7) water distribution is unaffected by the wind, and 8) it doesn't interfere with spraying, picking and hailing.

Trickle irrigation has been successfully used with fruit that contain considerable moisture when harvested (such as tomatoes, citrus, deciduous fruits) and has also been successfully used with many vegetables. But trickle irrigation is not practical or economical for closely planted crops such as cereal grains and pangola.

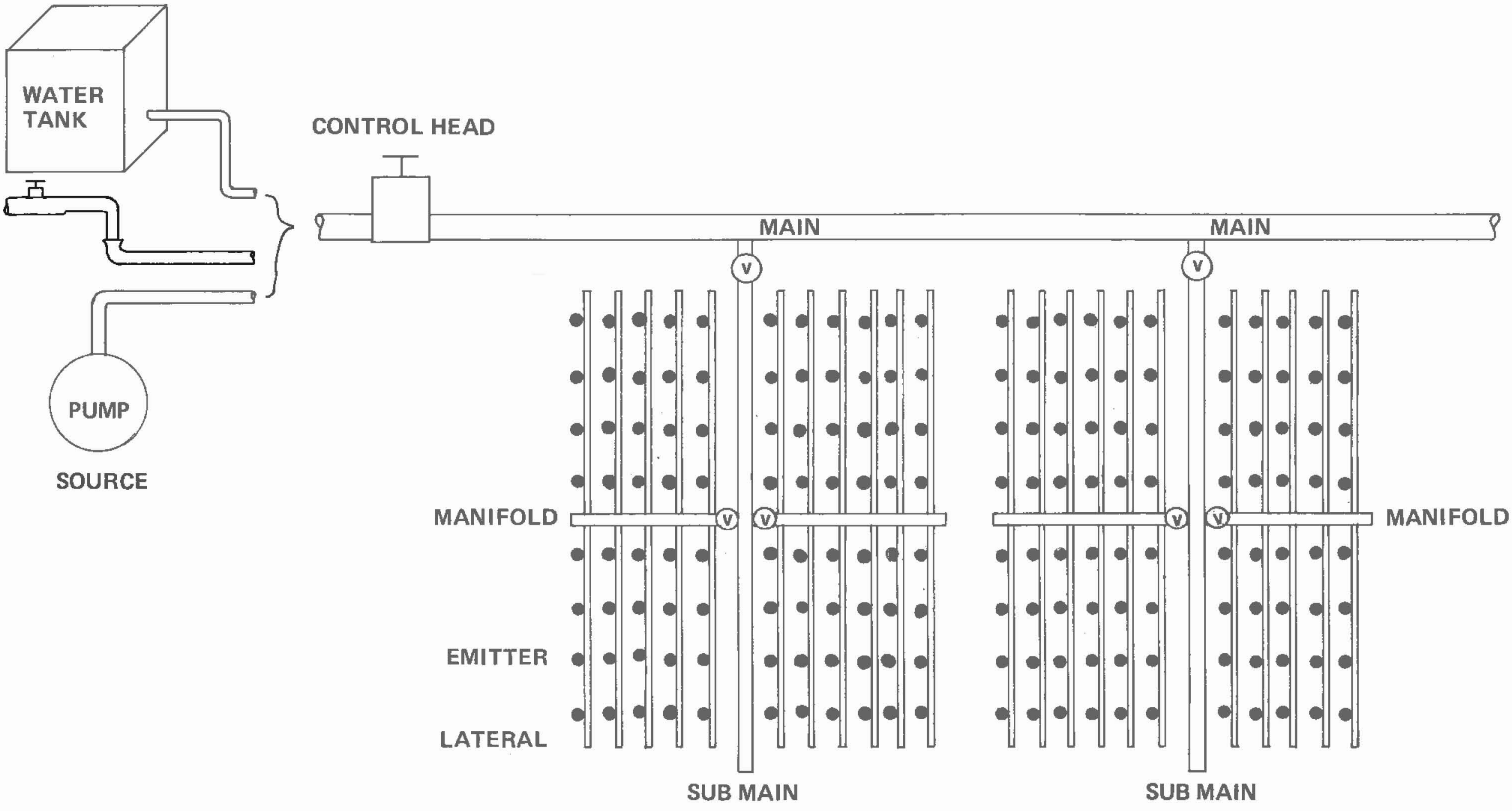
The major disadvantage of trickle irrigation is the greater potential for system clogging due to small passageways. This means that trickle irrigation requires a higher level of maintenance and management if the system is to be successful in realizing its full potential. This greater degree of vigilance is usually more than worth it.

In Figure 3.9 is a sketch depicting a typical trickle irrigation system, showing its basic components. Some systems, especially smaller systems may not have submains.

As one can see from the sketch, water flows from its source (under pressure supplied by a pump or gravity) first through the control head, then through the mainline, through the submains, the manifolds, the laterals, and finally trickles out through the emitter. From the emitter water spreads laterally and vertically through the soil by soil capillary forces, augmented in the vertical movement by gravity. The two extremities of the system (the control head and emitters) are most important in maintaining system efficiency.

Because trickle irrigation works under such low operating pressure. systems can be connected directly to the tap water lines if the system is not too large. When using tap water the fluctuations in pressure should not be too great or too frequent or it will have adverse effects on system operation. In many cases tap water will be unsuitable and pumping necessary. The irrigation water can originate from a well, a dam, rainwater storage tank, stream, etc., but one must keep in mind that the quality of the water entering this delicate system is very important.

Fig 3.9 SKETCH OF A TRICKLE IRRIGATION SYSTEM



V = VALVE
● = EMITTER VALVE

Filtration System

An appropriate filtration system should be selected to keep lines and emitters unclogged.

Clogging is caused by 1) solid particles in suspension; 2) micro-organisms and organic matter and for 3) chemical percipitation.

Accordingly, the filter is vitally important to a successful trickle system. The particle size tolerated in the system depends on the emitters used and such information should be supplied by the emitter manufacturer or known from local experience. The particle should be several times smaller than the emitter passageway because groups of particles tend to bridge the passageway.

Screen filters are the simplest and provide the most efficient means for filtering fine sands from the water. The screen filter basket should be made of plastic or non-corroding metal. Graded sand filters are also good for the removal of fine sand. But screen filters or graded sand filters tend to be rapidly clogged by heavy loads of algae and other organic materials, thus in such cases where the water has this higher level of pollutants. One should include vortex sand separator, gravel packs, or settling ponds.

Control Head

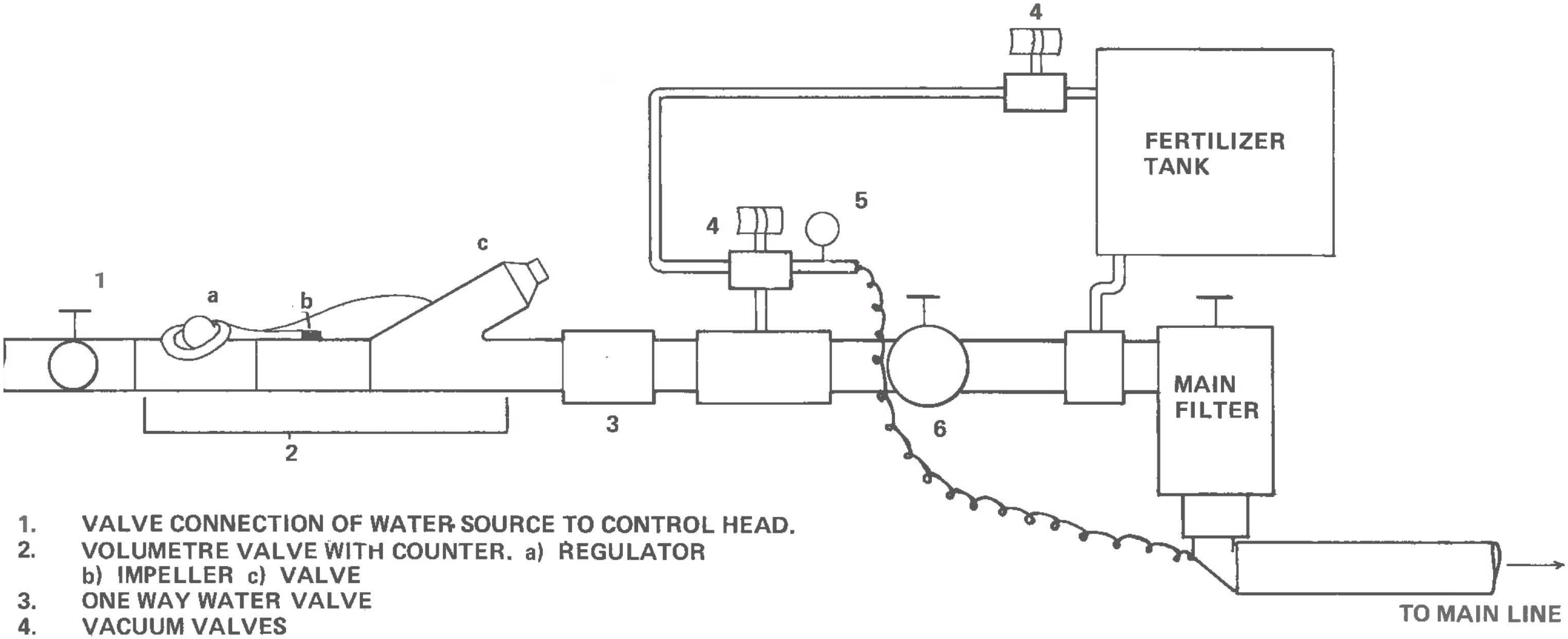
The filter is only one of many components of the water quantity/quality control unit at the head of the trickle system, more appropriately known as the "control head". A diagram of a control head is sketched below. (see Figure 3.10). Smaller and less complex control heads can be used, it all depends on the system size and the degree of quantity/quality control desired.

Although the main filter is located at the system control head, as a safety precaution additional secondary filters can be inserted at the entrance to the manifold or lateral lines. Here small filters or hose washer screens may be used.

Filters remove suspended solids but are not capable of chemical filtration. Small particles of algae also pass through the filtration system and it is important to keep them from growing inside the system. This is mainly accomplished by tinting all drip system components black during manufacture (most algae need light to grow, in darkness bacteria break down the algae). If algae do manage to invade the system despite these precautions, chlorine treatment is used. Five hundred ppm of chlorine in form of household bleach, calcium hypochlorite, sodium hypochlorite or gaseous chlorine under pressure injected and left in the system for 24 hours, then flushed normally is usually very succesful in eliminating algae. If Bacteria slime becomes a problem, it too can be treated with cholrine. Two to three ppm of chlorine left for 30 minutes in the system, treatment to continue 2-3 times/week until problem disappear. Intermittent chlorine treatment to prevent problem is also a good idea.

Chlorine is not the only chemical that can be injected into the drip irrigation system. A drip system is complete only if provision is made for fertilizer injection at the control head. But the injection of fertilizers is a matter that should be dealt with carefully; many fertilizers should not be considered due either to lack of solubility, or it provokes precipitation.

Fig 3.10 SKETCH OF A CONTROL HEAD FOR A TRICKLE IRRIGATION SYSTEM



1. VALVE CONNECTION OF WATER SOURCE TO CONTROL HEAD.
2. VOLUMETRE VALVE WITH COUNTER. a) REGULATOR
   b) IMPELLER c) VALVE
3. ONE WAY WATER VALVE
4. VACUUM VALVES
5. DIFFERENCIAL MANOMETER
6. MAIN PRESSURE CONTROL VALVE

For example, phosphorus cannot be considered for fertigation (fertilizing through irrigation) in water with a high quantity of calcium because phosphorus reacts with calcium to form dicalcium phosphate which can cause severe clogging. Well water or water originating from aquifers usually contain a high quantity of calcium. Unfortunately much of Barbados' water contains much calcium, thus phosphorus cannot be applied through fertigation.

The other major fertilizers can be used in fertigation in Barbados if used in the correct form. For example, nitrogen can be used in the forms of ammonium sulfate, ammonium nitrate, urea, anhydrous ammonia, as well as others. Sometimes adding nitrogen in the form of gaseous ammonia may cause a rise in water pH and cause precipitates of calcium.

Fertilizer solution can be either injected into the system by small pumps, poured into the pumpdump, or placed in a pressure tank and drained into the system by differential pressure. For more detailed information about fertigation please refer to the references given in the bibliography or contact Irrigation Department, Ministry of Agriculture, Barbados.

Control System

Also at the control head we have water quantity controls which range from fully automatic to manual. Time control, volume control or feedback control are the three main types of automatic controls. Time controls turn water on and off depending on the volume of water that has been delivered. Feedback controls turns water on and off at predetermined times. A volume control system turns water on and off depending on the volume of water that has been delivered. Feedback controls turns water on and off in response to moisture sensing devices placed in the irrigated area. Of course automatic controls can be fairly expensive, and although automatic controls do save time and labour, one can still have an efficient with totally manual controls. Hand operated controls and on-off valves at the inlet to each subunit (group of laterals controlled as a unit) require little labor and still allow the main activity of the irrigation, other than scheduling, to be seeing that the filter is kept clean.

To control system pressure there should be a pressure control valve and monitor at the system control head. To help insure uniform emitter discharge throughout the system additional pressure controller can be placed at the entrance to the laterals and manifolds, or alternatively accomplished by design, appropriate sizing of laterals or amnifolds where practical.

Design of the System

In the design of the system there should be allowance for reserve pressure to compensate for reduced flow due to clogging, and to help eliminate the need for frequent cleaning or replacement of emitters. Adding reserve pressure can never take the place of a good filter to keep a constant emitter flow, but it should be seen as further insurance against severe losses is a better solution to combat emitter performance deterioration than providing extra system capacity because extra system capacity means larger pump and pipe size while reserve pressure onlt means a slightly larger pump. Reserve pressure is no longer a good solution once emitter characteristics have degenerated 10-20 percent, and at this point replacing or cleaning emitters is the only solution.

Moving away from the control head and toward its eventual exit, water passes through the mainlines, the submains, and manifolds.

To help prevent clogging, these pipes should be made of non-corroding, non-scaling materials. Usually these pipes are made of polyethylene (PE) or rigid polyvinylchloride (PVC) and buried to facilitate farming operations. Cement asbestos, filament wound epoxy, and epoxy coated steel are also used for these pipes.

From the manifolds the water enter the narrower laterals (between 12-32 mm in diameter). The laterals are usually constructed of flexible PVC or PE hose for normal above ground use in contrast to the main, submain and manifold which are usually below ground. The necessity for extra materials and labor for installation, make below ground laterals less economical. Polyethylene costs approximately 30 percent less than PVC, but PE also has a shorter life expectancy and is less flexible than PVC.

Emitters

Attached to the laterals are several emitters which distribute the required water to the plants. There are several types of emitter-lateral connections for varying crops and crop spacings. (see Figure 3.11).

All arrangements aim to achieve a satisfactorily percentage of wetted soil. The percentage wetted area compared to the whole area. P, depends on the discharge and spacing of the emitters (or emission points in the case of multi-exit emitters) and soil type. A reasonal design objective is to wet a minimum of 1/3 (33 percent) of the poted root volume of widely spaced crops. In closely spaced crops it may he necessary to wet most of the soil volume (this is a major reason why irrigation losses its edge over other irrigation methods with close spaced crops; many advantages of drip depend on a small P).

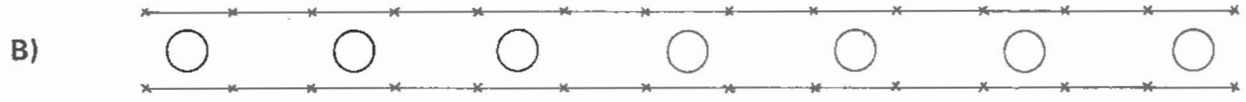
An emitter is a small item made of PVC, PE, and/or acrilonitrite butadiene (ABS) which allows water to desperse under low pressure in exact pre-determined pattern.

An emitter should satisfy the following requirements: 1) give relatively low but uniform constant discharge which does not vary significantly because of minor differences in pressure. It is preferable that the discharge-pressure relationship remain valid for a long period of time (years). With each emitter a chart displaying the relationship between pressure and discharge should be supplied. 2) The emitter should have a relatively large flow cross-section in order to reduce clogging problems. The smallest dimension of emitter flow path vary from .3mm in emitters very sensitive to clogging to 1.5mm in emitter relatively insensitive to clogging. Small deviations in the passageway result in relatively large deviations in discharge, thus it is important to obtain information pertaining to anticipated variation in emitter discharge. Some manufacturers supply v, the coefficient of variation which is the standard deviation divided by the average of all the emitter discharges from a test sample operated at the reference pressure. A good value for v is .06 or less. 3) The emitter connection itself causes pressure loss in the lateral and this information should be applied by the manufacturer to allow for more efficient design.

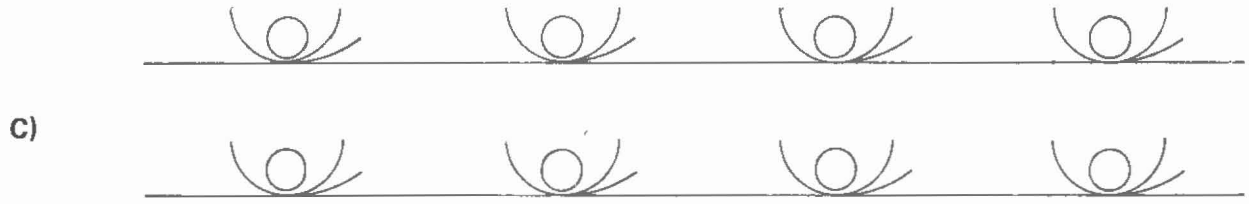
Types of Emitters

There are several types of emitters, they include microtubes (sometimes called spaghetti or whiskers), single exit long path emitters, multi-exit long path emitters, single or multi-exit orifice emitters, orifice vortex emitters, bi-wall emitter/lateral, pressure compensating emitter, automatic

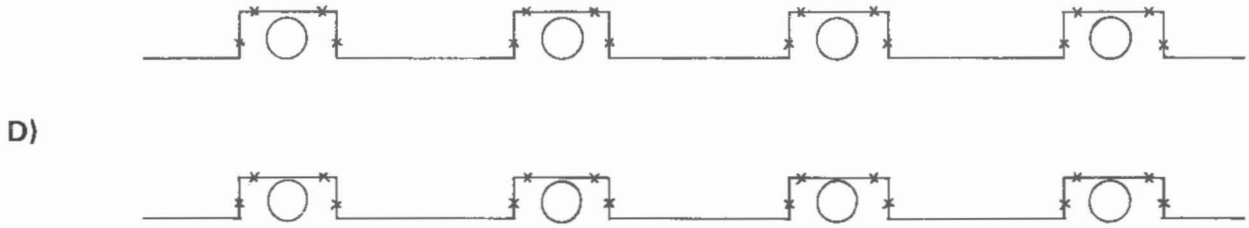
ONE LATERAL ROW CROPS



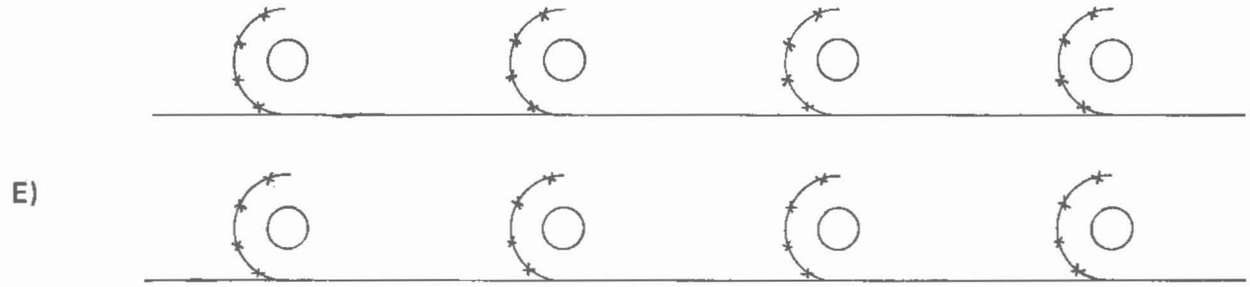
TWO LATERAL ROW CROPS



MULTI-EXIT EMITTERS WITH MICRO-TUBES



ZIG-ZAG SINGLE LATERAL FOR EACH ROW OF TREES



PIGTAIL WITH EMITTERS CONNECTED TO LATERAL

——— = LATERAL

○ = CROP/TREE

x = EMITTER

FIG 3.11 LATERAL ARRANGEMENTS TO IRRIGATE VEGETABLE CROPS OR FRUIT TREES.

flushing emitters, as well as a few more at the experimental stage.

1) Microtube emitters consist of a narrow guage plastic tube fed from a lateral. The normal internal diameter of the microtube range from .5 - .8 mm. Due to increased friction, the longer the tube, the slower the emitter flow rate. Thus one real advantage of microtubes is that they can be used to compensate for pressure changes along the lateral to uniform flow throughout the system. The major problem with microtubes outside the greenhouse is the constant risk that the lock of the tubes may be altered by wind, temperature, or cultivation practices. Microtubes are very effective in greenhouses where there is tube per potted plant.

2) Single exit long path and multi-exit long path emitters employ the same principle as lone microtubes in that the flow rate of water is decreased by sending the water through a long narrow passageway. But in long path emitters the path is in the form of a labyrinth cast on an inner cylinder which is inserted into a close fitting outer. Multi-exit long path emitters employ the use of several microtubes which branch out of the emitter instead of the lateral. Multi-exit emitters are usually used in orchards with widely spaced trees for the prupose of increasing the wetted area around the tree without increasing the number of laterals (and subsequently the cost). Although there is the same risk of dislocation of tubes, multi-exit long path emitters are easier to maintain than microtubes alone because of wide spacings and more reliable fittings.

Flow in long path single exit emitters are sensitive to temperature variations. Since many emitters are calibrated for a temperature in the vicinty of 20 degrees centigrade, discharges must be estimated in other temperatures by using a formula or a table.

Most orifice emitters clog easily. Automatic flushing orifice emitters have self cleaning capability. Flushing takes place at low pressure (at the beginning and end of each irrigation cycle). But the added feature increases the number of moving parts in the emitter which in itself may increase the likelihood of malfunction.

3) The vortex emitter has an orifice containing a circular cell which causes vortical flow. The vortical motion is achieved by the entrance of the water being tangent to the inner wall. The maximum decrease in charge is approx. 1/3 the flow of a simple orifice of the same diameter with the ratio between the entrance and its cell diameters ranging between 1:4 and 1:7. Therefore, for the same discharge and loss, the entrance diameter of a vortex can be approx. 1.73 (square of 3) times larger than a simple orifice emitter. These vortex emitters are less clog-prone than simple orifice emitters.

4) In bi-wall emitters a small number of widely spaced holes main bore with the auxilliary bore. The outer wall is provided with up to 10 times as many holes as the inner wall. These holes are the same. The inner holes are the pressure dissipators. Thus the inner chamber much higher pressure than the outer chamber. Bi-wall emitters are used with the more closely spaced crops. Its major advantage is that it is relatively inexpensive and it discharges a small quantity of water at a time, thus less energy is required. Its disadvantages include the holes tend to enlarge with time, it is

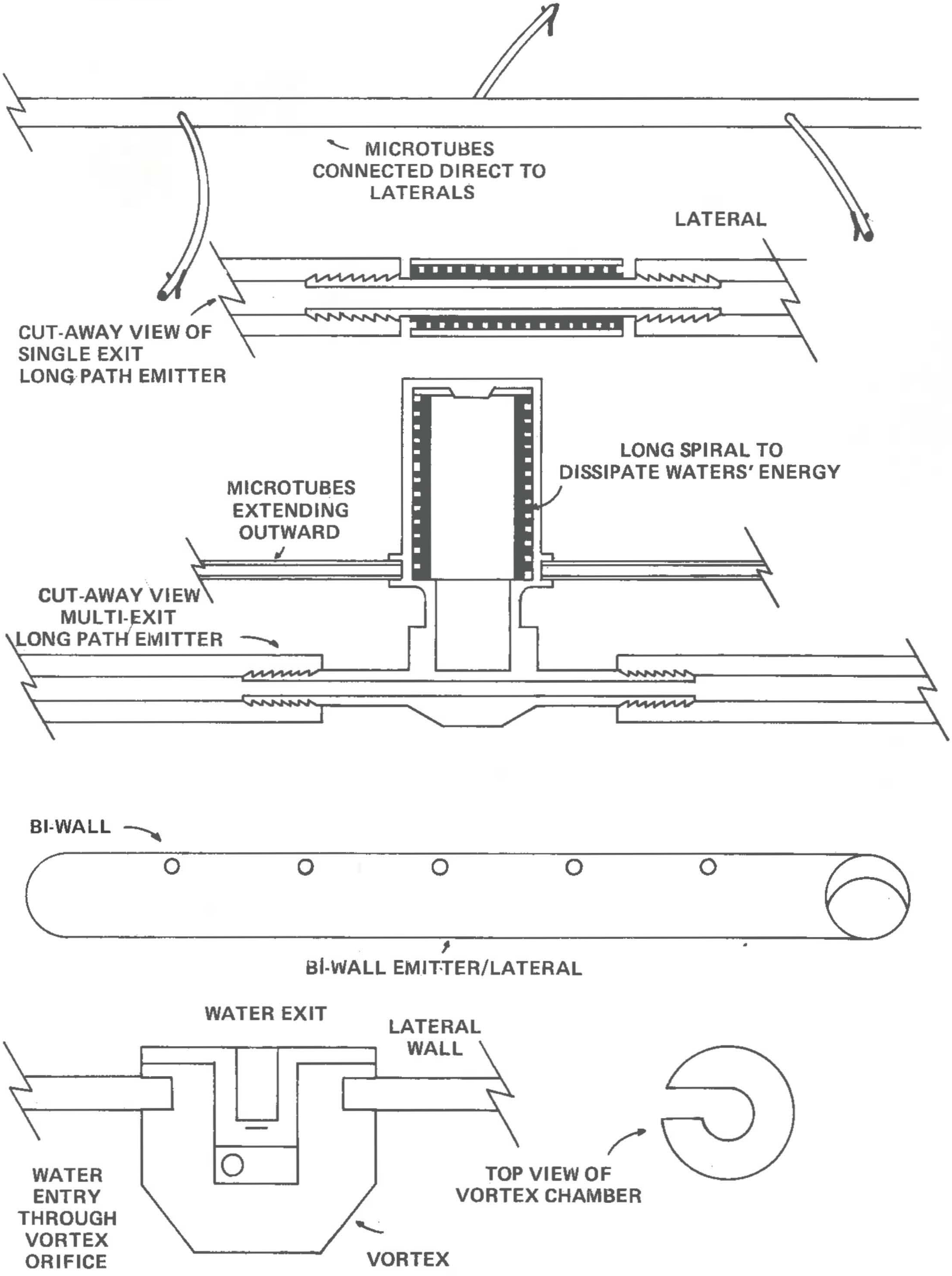


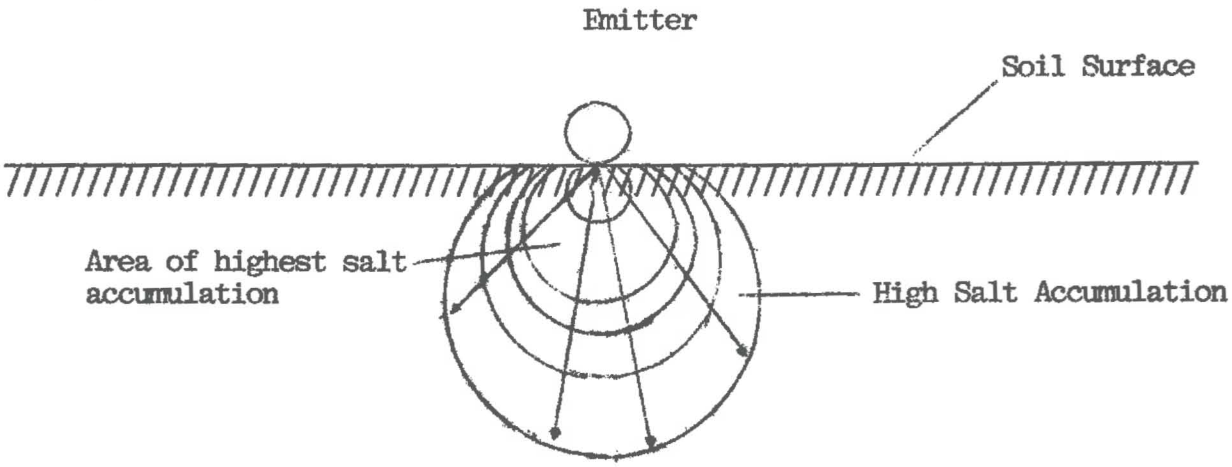
Fig. 3.12 TYPES OF EMITTERS

more subject to physical dam and its performance is very sensitive to hilly lands.

5) Flow compensating emitters are designed to discharge water at a constant rate over a wide range of lateral line pressures. A peculiar problem with compensating emitters is that the resilient material may distort over a period of time and gradually squeeze off the flow even though the pressure remains constant. Flow compensating emitters are valuable chiefly on hilly sites where it is impractical to design for uniform pressure along the laterals and manifolds.

FIGURE 3.13

TRICKLE IRRIGATION WATER FLOW AND SALT ACCUMULATION



Water flows out of the emitter into the ground as depicted above. Contour lines indicate zones of equal moisture content and lines radiating from the emitter show direction of water flow. Please note that the outer perimeter of the wetted area is the area of highest salt accumulation. If there is a rainy season the salt may be naturally leached out, if not the area may have to be sprayed with water every few seasons to artificially leach out the excess salts. This is a greater problem with some lands than with others.

Trickle irrigation requires more careful filtration, fertigation, and maintenance practices than other irrigation methods. Good maintenance means that filters be kept in good operating condition (it is expensive to detect, clean, or replace a clogged emitter thus preventative medicine is the best here), but it is also good practice to occasionally make sample checks to help insure that emitter discharge is uniform and sufficient. Pressure guages are used to check the difference in pressure across the filter indicating the degree of clogging in the filter. It is customary to clean the filter when the pressure drop is about 2 meters (6.6 feet). Filters can be cleaned manually or by back-flushing. Secondary filters on laterals and /or manifolds must be periodically checked also.

Provisions should be made for flushing the mainline, manifolds, submains, and laterals, which is usually done by having flush valves at the ends of these lines. Flushing the system is necessary because sand, silt and clay tend to settle in the slow flow regime at the ends of manifolds and laterals. Flushind should be done twice annually (at least).

Extreme caution in keeping large dirt particles from entering and possibly ruining the system is a must. An accident such as a mainline break could open up the system to enough sand or organic particles to ruin the system, possibly making it necessary to take the entire system apart.

It should be emphasized that the purpose of this section is to give a general overview of trickle irrigation. For those who wish to further pursue the possibilities of installing trickle irrigation onto their farms or gardens, further information concerning actual design (determining emitter type and sizes, determining emitter and spacing, lateral spacing, pipe sizes, fertilizer application rates, etc.) can be obtained from the listed bibliography or information or design help can be obtained from the Irrigation Department, Barbados Ministry of Agriculture, Food and Consumer Affairs.

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2. HANSEN, V.E. Irrigation Principles and Practices. John Wiley and Son Pub.
3. KELLER, J. and KARMEL, David. Trickle Irrigation Design. Rainbird Sprinkler Manuf. Corp.
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Tables from

Chapter 3 (section A)

Table: 3.1

MAXIMUM PRECIPITATION RATES TO USE ON LEVEL GROUND

Good Conditions	Poor Conditions
Bare ground	Bare ground
Good soil aggregation	Poor soil aggregation
High organic content	Low organic content
Open granular structure, no evidence of sealing	Thin sealed layer at surface

Soil	Basic Intake Rate	Reduce to
Coarse sands	0.75-1.00 iph	0.35 iph
Fine sands	0.50-0.75 iph	0.25 iph
Fine sandy loams	0.35-0.50 iph	0.20 iph
Silt loams	0.25-0.40 iph	0.12-0.15 iph
Clay loams	0.10-0.30 iph	0.05-0.10 iph

Table: 3.2

SLOPE PRECIPITATION

Slope	Precipitation rate reduction
0-5% grade [1]	0%
6-8% grade	20%
9-12% grade	40%
13-20% grade	60%
Over 20% grade	75%

---

[1] eg: 5% grade is a fall (or rise) of 5ft in 100ft.

Table: 3.3

ESTIMATING IRRIGATION EFFICIENCIES

Desert Climate	65%
Hot, dry Climate	70%
Moderate Climate	75%
Humid or cool Climate	80%

Assuming 70% for our conditions, then the gross amount of **application** at the sprinkler nozzlers must be:-

$$\text{Gross amount of application} = \frac{\text{Peak use application}}{\text{Irrigation efficiency in decimals}}$$

$$\text{Gross amount of application} = \frac{1.5\text{ inch}}{0.7} =$$

$$\text{Gross amount of application} = 2.14\text{ inches}$$

Table: 3.4

TYPICAL COEFFICIENTS OF UNIFORMITY(C_u)

Spacing	2 m.p.h Wind	9 m.p.h Wind
40'x 40' Rectangular	92%	84%
50'x 50' Rectangular	88%	63%
60'x 60' Rectangular	80%	31%

Minimum acceptable C_u generally recognised as 80% -85%.

Table: 3.5

MAXIMUM SPRINKLER SPACING ACCORDING TO WIND, BASED ON DIAMETER OF COVERAGE

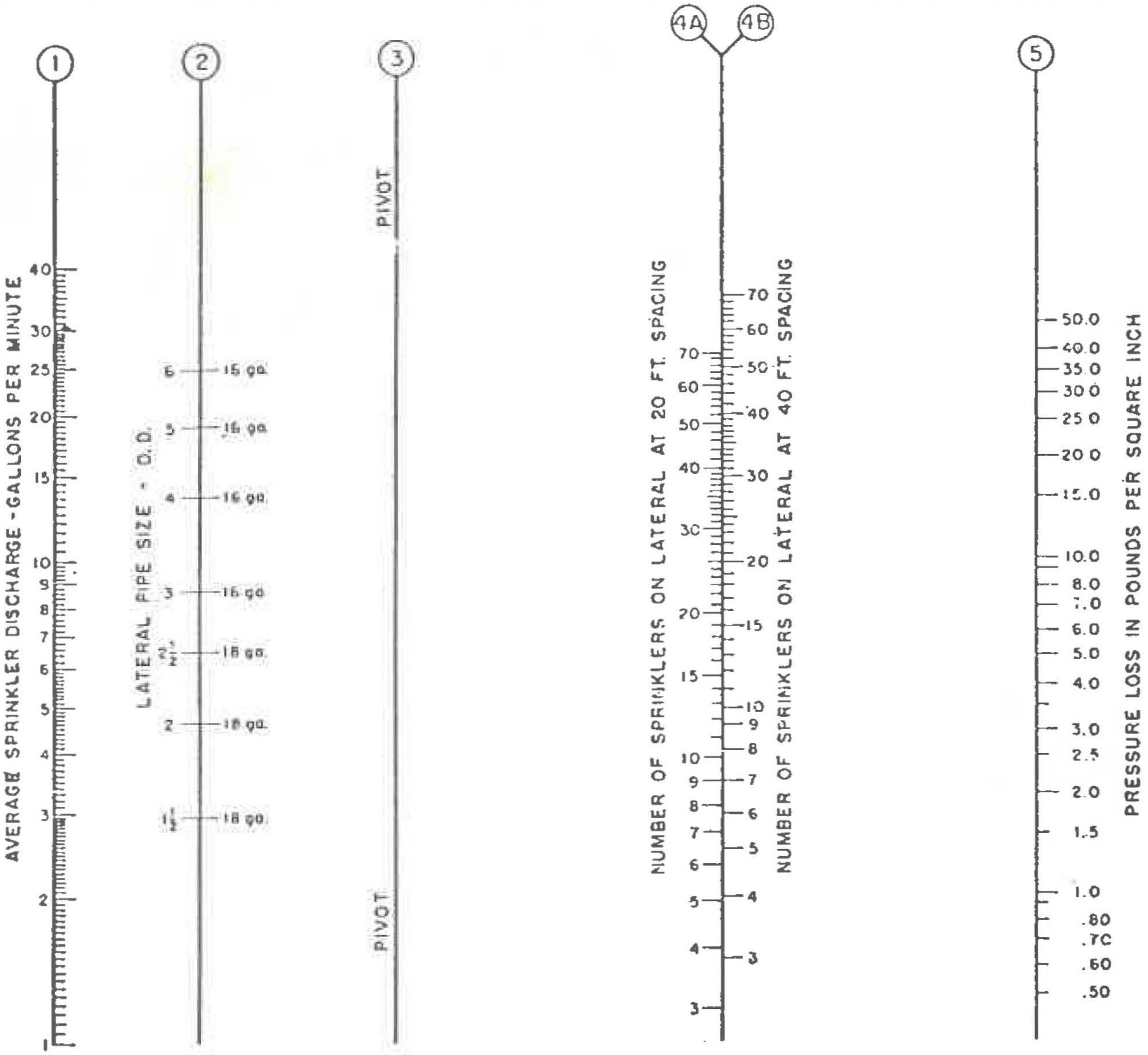
Rectangular spacing (wind predominantly from one direction)

Average wind speed	Spacing	
	On Lateral	Between Laterals
Up to 7 m.p.h	40%	65%
7 to 10 m.p.h	40%	60%
Over 10 m.p.h	30%	50%

APPENDIX 1 NOMOGRAPH 1

PRESSURE LOSS IN PORTABLE SPRINKLER LATERALS

Based on Scobey's formula with values of Ks and multiple outlet factors as recommended by:- J. E. Christiansen.*



PROCEDURE: To find lateral size or combination of lateral sizes which will result in 10% or less variation in sprinkler discharge.

Given: (a) Average sprinkler discharge for all sprinklers on the lateral, (b) average operating pressure required and (c) number of sprinklers on lateral.

Step No.1 Compute 20% of average pressure (b) and locate on on scale ⑤

Step No.2 Find number of sprinklers on lateral on scale (4A) for 20' spacing or (4B) for 40' spacing. Connect points on scales 5 and (4A) or (4B) and extend to scale ③ (Pivot line) **

Step No.3 Connect point on ③ with value for average sprinkler discharge on scale ①

Step No.4 Read on scale ② the lateral size required. If the line connecting scales ① and ③ intersects scale ② between two pipe sizes, the approximate proportion of the two sizes may be determined by estimating the proportional inverse distances between the point of intersection and the pipe size point on the scale.

*Reference "Irrigation by Sprinkling" by J.E. Christiansen Univ. of California, Bulletin 670, Figure 26.

** For spacing other than 20' or 40', use the following procedure.

(a) *Compute 20% of average operating pressure*

(b) *Multiply value obtained by* $\frac{20}{Spacing}$ *and then use the value obtained to start on scale* ⑤

(c) *Follow steps No 2 to 4 using scale* (4A)
If lateral of known size is to be analyzed for pressure loss, use scale (4A) *and then multiply value obtained on scale* ⑤ *by* $\frac{Spacing}{20}$

Source: Gray, A.Sprinkler Irrigation Handbook. Rainbird Sprinkler. MFG Corporation Glendora, California 7th Edition, 1961.

APPENDIX 2 NOMOGRAPH 2

FRICTION LOSS FOR SPRINKLER SYSTEM MAIN LINES

CLASS OF PIPE	Scobey Ks	Hazen-Williams C	Manning n
New—Smooth Spiral-welded Steel	0.32	140	009
New—Aluminum⁴	0.32	140	009
Transite	0.32*	140	009
Spiral-welded Steel—15 Years	0.40*	120	.012
Full Riveted Steel Pipe—10 Years	0.44*	110	.014
Reclaimed Invasion Pipe	0.52*	95	.017
Wood Stave Pipe—New	0.40	120	.012
Wood Stave Pipe—15 Years	0.44*	110	.014
Portable Aluminum and Couplers	0 40*	120	.012
Portable Galvanized Steel and Couplers	0 42*	115	.013

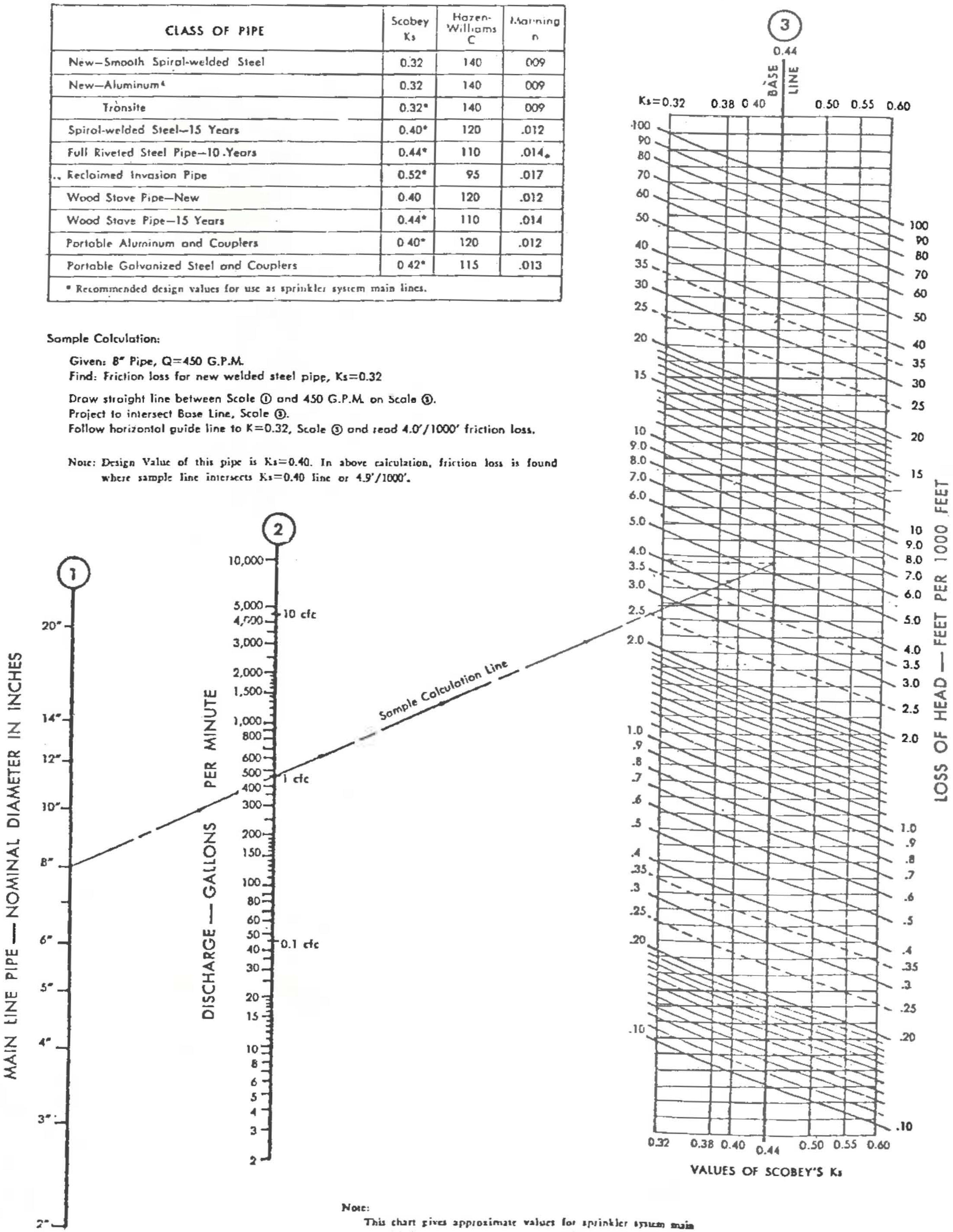
* Recommended design values for use as sprinkler system main lines.

Sample Calculation:

Given: 8" Pipe, Q=450 G.P.M.
Find: Friction loss for new welded steel pipe, Ks=0.32

Draw straight line between Scale ① and 450 G.P.M. on Scale ②.
Project to intersect Base Line, Scale ③.
Follow horizontal guide line to K=0.32, Scale ③ and read 4.0'/1000' friction loss.

Note: Design Value of this pipe is Ks=0.40. In above calculation, friction loss is found where sample line intersects Ks=0.40 line or 4.9'/1000'.



Note:

This chart gives approximate values for sprinkler system main line friction loss, based on average pipe thickness. For high capacities or long lines (over 3000 feet) use tables or charts given for each class of pipe.

Source: Gray, A.Sprinkler Irrigation Handbook. Rainbird Sprinkler. MFG Corporation Glendora, California 7th Edition, 1961.

APPENDIX 3

FULL CIRCLE IMPACT SPRINKLERS / 20 SERIES

PERFORMANCE FOR 20JH
Highest point of stream is 7′ above nozzle.*

P.S.I. @ Nozzle	Nozzle 3/32″ Dia.	Nozzle 3/32″ GPM	†Nozzle 7/64″ Dia.	†Nozzle 7/64″ GPM	Nozzle 1/8″ Dia.	Nozzle 1/8″ GPM	Nozzle 9/64″ Dia.	Nozzle 9/64″ GPM
35	72	1.51	76	2.13	77	2.75	78	3.43
40	73	1.62	77	2.27	78	2.94	80	3.66
45	74	1.72	78	2.40	79	3.11	80	3.87
50	74	1.80	78	2.53	79	3.27	81	4.08
55	75	1.88	78	2.65	80	3.43	81	4.27
60	75	1.98	79	2.76	80	3.57	82	4.45

PERFORMANCE FOR 20EJH
Highest point of stream is 7′ above nozzle.*

P.S.I. @ Nozzle	Nozzle 3/32″ Dia.	Nozzle 3/32″ GPM	†Nozzle 7/64″ Dia.	†Nozzle 7/64″ GPM	Nozzle 1/8″ Dia.	Nozzle 1/8″ GPM	Nozzle 9/64″ Dia.	Nozzle 9/64″ GPM
35	75	1.51	77	2.13	79	2.75	82	3.43
40	76	1.62	78	2.27	80	2.94	83	3.66
45	77	1.72	79	2.40	81	3.11	84	3.87
50	78	1.80	80	2.53	82	3.27	85	4.08
55	79	1.88	81	2.65	82	3.43	86	4.27
60	79	1.98	81	2.76	82	3.57	87	4.45

20JH/20EJH

All-new sprinkler including **"H" bearing;** widely used in all types of permanent systems, on center pivots and in general field applications. Rugged enough for hand move and solid set systems. Now cataloged with 3/32″ nozzle. Excellent performance extended in low to medium application rates. Performance is maintained under windy conditions with non-clog vane in "E" model. ½″ male bearing.

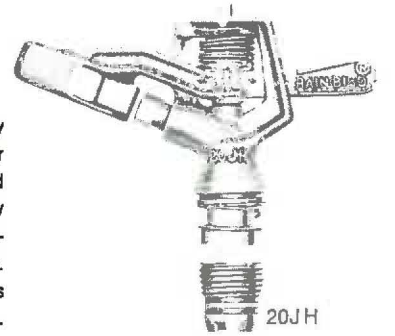


Fig. 3.5 (a)

PERFORMANCE FOR 20AH 7° Highest point of stream is 3′ above nozzle (aluminum arm model).*

ALUMINUM ARM

P.S.I. @ Nozzle	†Nozzle 7/64″ 7° Dia.	†Nozzle 7/64″ 7° GPM	Nozzle 1/8″ 7° Dia.	Nozzle 1/8″ 7° GPM	Nozzle 9/64″ 7° Dia.	Nozzle 9/64″ 7° GPM
15	—	—	43	1.75	45	2.20
20	43	1.55	45	1.97	47	2.53
25	45	1.73	47	2.21	49	2.83
30	47	1.89	49	2.44	51	3.10
35	48	2.05	51	2.66	53	3.36
40	50	2.20	52	2.86	54	3.61
45	51	2.32	54	3.04	56	3.82
50	52	2.44	55	3.22	57	4.03

BRONZE ARM

P.S.I. @ Nozzle	†Nozzle 5/32″ 7° Dia.	†Nozzle 5/32″ 7° GPM	Nozzle 11/64″ 7° Dia.	Nozzle 11/64″ 7° GPM	Nozzle 3/16″ 7° Dia.	Nozzle 3/16″ 7° GPM	Nozzle 13/64″ 7° Dia.	Nozzle 13/64″ 7° GPM	Nozzle 7/32″ 7° Dia.	Nozzle 7/32″ 7° GPM
15	47	2.68	48	3.24	50	3.91	52	[illegible]	[illegible]	[illegible]
20	49	3.04	50	3.72	52	4.33	54	5.13	57	[illegible]
25	51	3.43	52	4.17	54	4.87	56	5.75	59	[illegible]
30	53	3.78	54	4.57	56	5.35	58	6.30	61	7.20
35	54	4.10	55	4.96	57	5.84	60	6.83	63	7.79
40	56	4.40	57	5.32	59	6.27	62	7.31	65	8.35
45	57	4.68	58	5.65	60	6.66	64	7.76	67	8.88
50	59	4.95	60	5.95	62	7.03	65	8.18	69	9.38

PERFORMANCE FOR 20AH 12° Highest point of stream is 4′ above nozzle (aluminum arm model).*

ALUMINUM ARM

P.S.I. @ Nozzle	†Nozzle 7/64″ 12° Dia.	†Nozzle 7/64″ 12° GPM	Nozzle 1/8″ 12° Dia.	Nozzle 1/8″ 12° GPM	Nozzle 9/64″ 12° Dia.	Nozzle 9/64″ 12° GPM
20	47	1.55	50	1.97	50	2.53
25	49	1.73	52	2.21	52	2.83
30	51	1.89	54	2.44	55	3.10
35	54	2.05	55	2.66	57	3.36
40	55	2.20	57	2.86	58	3.61
45	56	2.32	59	3.04	60	3.82
50	58	2.44	60	3.22	61	4.03

BRONZE ARM

P.S.I. @ Nozzle	†Nozzle 5/32″ 12° Dia.	†Nozzle 5/32″ 12° GPM	Nozzle 11/64″ 12° Dia.	Nozzle 11/64″ 12° GPM	Nozzle 3/16″ 12° Dia.	Nozzle 3/16″ 12° GPM	Nozzle 13/64″ 12° Dia.	Nozzle 13/64″ 12° GPM	Nozzle 7/32″ 12° Dia.	Nozzle 7/32″ 12° GPM
20	51	3.04	52	3.72	54	4.33	57	5.13	60	5.90
25	54	3.43	56	4.17	56	4.87	60	5.75	63	6.56
30	56	3.78	58	4.57	59	5.35	62	6.30	65	7.20
35	58	4.10	59	4.96	61	5.84	64	6.83	68	7.79
40	60	4.40	61	5.32	63	6.27	66	7.31	70	8:35
45	61	4.68	63	5.65	64	6.66	68	7.76	71	8.88
50	63	4.95	64	5.95	66	7.03	69	8.18	73	9.38

PERFORMANCE FOR 20AH 20° Highest point of stream is 4′ above nozzle (aluminum arm model).*

ALUMINUM ARM

P.S.I. @ Nozzle	†Nozzle 7/64″ 20° Dia.	†Nozzle 7/64″ 20° GPM	Nozzle 1/8″ 20° Dia.	Nozzle 1/8″ 20° GPM	Nozzle 9/64″ 20° Dia.	Nozzle 9/64″ 20° GPM
20	50	1.55	51	1.97	52	2.53
25	53	1.73	54	2.21	55	2.83
30	55	1.89	57	2.44	58	3.10
35	57	2.05	59	2.66	60	3.36
40	59	2.20	61	2.86	62	3.61
45	61	2.32	63	3.04	64	3.82
50	63	2.44	64	3.22	65	4.03

BRONZE ARM

P.S.I. @ Nozzle	†Nozzle 5/32″ 20° Dia.	†Nozzle 5/32″ 20° GPM	Nozzle 11/64″ 20° Dia.	Nozzle 11/64″ 20° GPM	Nozzle 3/16″ 20° Dia.	Nozzle 3/16″ 20° GPM	Nozzle 13/64″ 20° Dia.	Nozzle 13/64″ 20° GPM	Nozzle 7/32″ 20° Dia.	Nozzle 7/32″ 20° GPM
20	53	3.04	54	3.72	55	4.33	58	5.13	63	5.90
25	56	3.43	57	4.17	58	4.87	61	5.75	66	6.56
30	59	3.78	61	4.57	63	5.35	65	6.30	70	7.20
35	61	4.10	63	4.96	65	5.84	67	6.83	72	7.79
40	63	4.40	65	5.32	67	6.27	69	7.31	74	8.35
45	65	4.68	67	5.65	68	6.66	71	7.76	75	8.88
50	66	4.95	68	5.95	70	7.03	73	8.18	76	9.38

PERFORMANCE FOR 20AH 23° Highest point of stream is 5′ above nozzle (aluminum arm model).*

ALUMINUM ARM

P.S.I. @ Nozzle	†Nozzle 7/64″ 23° Dia.	†Nozzle 7/64″ 23° GPM	Nozzle 1/8″ 23° Dia.	Nozzle 1/8″ 23° GPM	Nozzle 9/64″ 23° Dia.	Nozzle 9/64″ 23° GPM
20	62	1.55	63	1.97	64	2.53
25	64	1.73	65	2.21	66	2.83
30	66	1.89	67	2.44	68	3.10
35	68	2.05	69	2.66	70	3.36
40	70	2.20	71	2.86	72	3.61
45	72	2.32	73	3.04	74	3.82
50	74	2.44	75	3.22	76	4.03

BRONZE ARM

P.S.I. @ Nozzle	†Nozzle 5/32″ 23° Dia.	†Nozzle 5/32″ 23° GPM	Nozzle 11/64″ 23° Dia.	Nozzle 11/64″ 23° GPM	Nozzle 3/16″ 23° Dia.	Nozzle 3/16″ 23° GPM	Nozzle 13/64″ 23° Dia.	Nozzle 13/64″ 23° GPM	Nozzle 7/32″ 23° Dia.	Nozzle 7/32″ 23° GPM
20	65	3.04	68	3.72	71	4.33	73	5.13	74	5.90
25	67	3.43	70	4.17	73	4.87	75	5.75	76	6.56
30	69	3.78	72	4.57	75	5.35	77	6.30	78	7.20
35	71	4.10	74	4.96	77	5.84	79	6.83	80	7.79
40	73	4.40	76	5.32	79	6.27	81	7.31	82	8.35
45	75	4.68	78	5.65	81	6.66	83	7.76	84	8.88
50	77	4.95	80	5.95	83	7.03	85	8.18	86	9.38

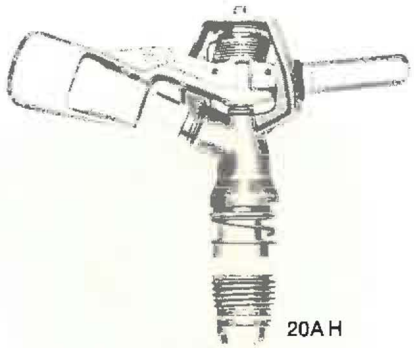


Fig. 3.5 (b)

20AH Series

This versatile model has a wide range of nozzle sizes and angles. Widely used in undertree permanent and solid set systems. Anodized aluminum arm with a brass bushing and neoprene bumper is used for small nozzles; the bronze arm for large nozzles. Gives good water patterns and wetted diameters without interference with tree skirt. (where required) because of the special nozzle designs. This sprinkler has the all-new **"H" bearing.** ½″ male bearing.

PERFORMANCE FOR 20AH 5°
Highest point of stream is 1.5′ above nozzle.*

P.S.I. @ Nozzle	Nozzle 7/64″–5° Dia.	Nozzle 7/64″–5° GPM	†Nozzle 1/8″–5° Dia.	†Nozzle 1/8″–5° GPM	Nozzle 9/64″–5° Dia.	Nozzle 9/64″–5° GPM	Nozzle 5/32″–5° Dia.	Nozzle 5/32″–5° GPM
15	—	—	48	1.82	47	2.68	48	2.55
20	40	1.43	47	1.88	48	2.41	49	3.07
25	47	1.60	48	2.10	49	2.71	50	3.35
30	48	1.78	49	2.31	50	2.98	51	3.66
35	49	1.95	50	2.49	51	3.23	52	3.97
40	50	2.12	51	2.67	52	3.46	53	4.25
45	51	2.29	52	2.83	53	3.68	54	4.52
50	52	2.46	53	2.99	54	3.89	55	4.77

---

†Standard nozzle. *Shown for standard nozzle at normal operating pressure. NON-SHADED AREAS IN CHART RECOMMEND WORKING PRESSURE FOR BEST DISTRIBUTION

Source: Rainbird Sprinkler MFG Corporation 1979-1980
Irrigation Equipment 1979.

APPENDIX 4

METRIC EQUIVALENTS

Spacing - 30' x 40' ≃ 9m x 12m

Precipitation Rate - 0.25 iph ≃ 6.4mm/hr

Diamter of throw - 80ft ≃ 24m

Pressure - 25 psi ≃ 3.2 atm

Discharge - 2.59 g.p.m (Imp) ≃ $0.7m^3/hr$

Nozzle Diameter - 1/8" = 3.2mm

CHAPTER 4

ANALYSIS COST OF SPRINKLER IRRIGATION IN BARBADOS

by
Victor Ojeda

1. INTRODUCTION

Farming is a business undertaken to achieve a sustained net income therefore the primary objective of irrigation is to increase farm production. A farmer cannot afford to use an irrigation system unless by so doing his total farm production and net income can be increased. Hence, it is necessary to determine all of the costs of an irrigation system. This total cost can be compared with the benefits received or the increase in income to determine what profit, if any, has been realized from the system. A farmer should not install an irrigation scheme if the estimate increase in the value of production will not exceed the additional cost of irrigation, including the capital cost of the equipment and its operation and maintenance.

The cost and return from the various types of sprinkler systems are a part of every feasibility report for any proposed sprinkler irrigation farm or project development.

A complete breakdown of the irrigation costs is necessary to help the purchaser have a full understanding of the annual expense involved with his sprinkler system so he may be guided to make the proper decision on his purchase and use. An analysis of sprinkler irrigation costs should not only show the initial cost, but also the annual costs per acre. Such costs should include the fixed as well as the operation and maintenance costs computed on an annual basis per acre to be irrigated.

A true analysis of costs must consider all direct cash and non-cash expenses for water application, together with the indirect effect of the irrigation practices on other operation costs. These costs must be compared with the increased income resulting from the sprinkler installation.

II CAPITAL INVESTMENTS

A. Equipment and Installation Costs

The equipment and installation cost must be known for the various components of a sprinkler irrigation system before the annual cost for irrigation system can be computed. Costs that must be considered are:-

1. Water supply cost:-	May include cost of water rights and the construction costs for wells.
2. Conveyance cost:-	The main line of a sprinkler system could be considered here and also other structures that might be needed to convey the water from the source to the sprinkler lateral.
3. Pump costs:-	This includes the cost of the main pump, bowls, column, and all booster pumps in the system, and their installation.
4. Power Unit Costs:-	The cost of power unit and its installation should be included. The power may be diesel, gasoline or electrical. Line construction costs for electrical installations should be included.

5. Distribution system cost:- The cost of sprinkler lateral pipes, risers, sprinkler heads, nozzles, pressure regulators or flow control devices, end plugs and valve opening elbows should be included in this category. Mainline pipe, risers, control valves and outlet valves should be included here if not included under conveyance systems,

6. Special equipment costs:- This includes the cost of soil moisture determination equipment, trailers for hauling and transporting pipe if used in the operation of the system. The installation costs for any of the above equipment should be included.

B. Building and Facilities

There are many costs such as road or trail construction to enable the delivery of equipment to the installation site, buildings for the protection and storage of equipment, and other miscellaneous costs that are chargeable to the capital investment when installing a sprinkler system, and all such expenditures should be included.

The total capital investment cost for the sprinkler system will be a summary of the above costs.

III ANNUAL IRRIGATION COSTS

The annual irrigation costs are composed of annual fixed costs and annual operation and maintenance costs.

A. Annual Fixed Costs

These are determined by the interest on the money expended for the facility, plus the capital loss, because of depreciation and also taxes and insurance. The procedure in calculating the annual fixed costs is to apply the Capital Recovery Factor, (Table 4.1) that combines depreciation and interest on investment into one number. In order to determine accurately how much the equipment costs per year, multiply the initial cost of equipment by the Capital Recovery Factor corresponding to the column of the selected compound interest rate and the estimated life of the equipment.(See Table 4.8 for example)

The Barbados National Bank offers loans for irrigation and the interest rate is 6% payable from 3-7 years. See appendix No. 1.

Table 4.2 shows the average life for various items. Other factors to be considered in determining the depreciation period in the life of the equipment are:-

- the type of service and care given to the equipment during use.
- the operating condition, care and maintenance.
- the off-season storage of equipment.

B. Annual Operation And Maintenance Costs

This includes the costs incurred for water, power (fuel or electricity), labour, lubrication and repairs to the equipment.

Table: 4.1 CAPITAL RECOVERY FACTOR

ESTIMATED LIFE IN YEARS	COMPOUND INTEREST RATE PERCENT						
	4	5	6	7	8	9	10
1	1.0400	1.0500	1.0600	1.0700	1.0800	1.0900	1.1000
2	.5302	.5378	.5454	.5531	.5608	.5685	.5762
3	.3604	.3672	.3741	.3810	.3880	.3951	.4021
4	.2755	.2820	.2886	.2952	.3019	.3087	.3155
5	.2246	.2310	.2374	.2439	.2504	.2571	.2638
6	.1903	.1970	.2034	.2098	.2163	.2229	.2296
7	.1666	.1728	.1791	.1856	.1921	.1987	.2054
8	.1485	.1547	.1610	.1675	.1740	.1807	.1874
9	.1345	.1407	.1470	.1535	.1601	.1668	.1736
10	.1223	.1295	.1359	.1424	.1490	.1558	.1627
11	.1142	.1204	.1268	.1334	.1401	.1469	.1540
12	.1066	.1128	.1123	.1259	.1327	.1396	.1468
13	.1001	.1065	.1130	.1197	.1265	.1336	.1408
14	.0947	.1010	.1076	.1143	.1213	.1284	.1357
15	.0899	.0963	.1030	.1098	.1168	.1241	.1315
16	.0858	.0923	.0990	.1059	.1130	.1203	.1278
17	.0822	.0887	.0954	.1024	.1096	.1170	.1247
18	.0790	.0856	.0924	.0994	.1067	.1142	.1219
19	.0761	.0828	.0896	.0968	.1041	.1117	.1195
20	.0736	.0802	.0872	.0944	.1019	.1095	.1175
25	.0640	.0710	.0782	.0858	.0937	.1018	.1102
30	.0578	.0650	.0726	.0806	.0888		
35	.0536	.0611	.0690	.0772	.0858		
40	.0505	.0582	.0665	.0750	.0839		
45	.0483	.0563	.0647	.0735	.0826		
50	.0466	.0548	.0634	.0725	.0817		

SOURCES: a) FAO. "Sprinkler Irrigation" Agricultural Development Paper No.88, 1968 .152p

b) WOODWARD, G. "Sprinkler Irrigation." Santa Monica, California. Sprinkler Irrigation Association. 1959.

Table 4.2 SUGGESTED DEPRECIATION PERIODS FOR COMPONENTS OF A SPRINKLER IRRIGATION SYSTEM

COMPONENT	POSSIBLE DEPRECIATION RANGE	SUGGESTED DEPRECIATION PERIOD
	YEARS	
-Well	5 - 50	35
-Pump	3 - 20	15
-Power Units		
Electric motor	10 - 30	25
Diesel	10 - 20	15
Gasoline air cooled	2 - 6	4
-Pump plant housing	10 - 30	20
-Buried cast iron and asbestos-PVC	20 - 50	35
-Plastic Pipe		
Buried	10 - 50	35
Exposed to sunlight	1 - 5	3
-Portable aluminum pipe	5 - 20	15
-Portable galvanized pipe	5 - 15	10
-Sprinkler valves	5 - 20	10
-Sprinkler head		8
-Bronze main line valves	20 - 50	35
-Wood flumes		8
-Power lines	20 - 50	35

SOURCE: FAO. "Sprinkler Irrigation." Agricultural Development Paper No. 88, 1968. 152p.

1. The annual power costs will depend on the type of power unit used, cost of fuel or energy and the overall efficiency of the pumping plant. Many engine manufactures give average values for fuel consumption in terms of gallons per brake horsepower. Fuel consumption will vary, depending on the condition of the engine and the manner in which it is maintained. Another factor which can be very important is if the operator increases the throttle settings beyond manufacturers recommendations, or if the planner of the irrigation system imposes an overloading condition to the engine. Tables 4.3 and 4.4 demonstrate the comparative fuel consumption per hour for internal combustion engines burning various types of fuel, for various total dynamic heads and gallons per minute being pumped.

Table 4.3. DIESEL FUEL CONSUMED, GALLONS PER HOUR

Lift (ft)	Gallons per minute of water being pumped									
	100	200	400	600	800	1000	2000	3000	4000	5000
50	0.1	0.2	0.5	o.7	o.9	1.2	2.3	3.4	4.6	5.8
100	0.2	0.5	0.9	1.4	1.8	2.3	4.6	6.9	9.1	11.5
200	0.5	0.9	1.8	2.7	3.7	4.6	9.2	13.7	18.3	22.9
300	0.7	1.4	2.8	4.1	5.5	6.9	13.7	21.6	27.5	34.4
400	0.9	1.8	3.7	5.5	7.3	9.2	18.4	27.5	36.8	45.8
500	1.1	2.3	4.6	6.8	9.1	11.4	22.8	34.4	45.5	57.0

SOURCE: WOODWARD, G. "Sprinkler Irrigation" Santa Monica, California. Sprinkler Irrigation Association. 1959.

Table: 4.4. GASOLINE CONSUMPTION, GALLONS PER HOUR

Lift (ft)	Gallons per minute of water being pumped									
	100	200	400	600	800	1000	2000	3000	4000	5000
50	0.15	0.3	0.6	0.9	1.2	1.5	3.0	4.5	6.0	7.5
100	0.3	0.6	1.2	1.8	2.5	3.0	6.0	9.0	12.0	15.0
200	0.6	1.2	2.4	3.6	4.8	6.0	12.0	18.0	24.0	30.0
300	0.9	1.8	3.6	5.3	7.1	8.9	17.8	26.7	35.6	44.5
400	1.2	2.4	4.8	7.1	9.5	11.9	23.8	35.7	47.7	59.5
500	1.5	3.0	6.0	8.9	11.9	14.9	28.9	44.7	59.5	-

SOURCE: WOODWARD,G. "Sprinkler Irrigation." Santa Monica, California. Sprinkler Irrigation Association. 1959.

Electric power schedules in Barbados are based on a fixed standby charge for the horsepower rating of the motor and a diminishing schedule rate for the energy actually consumed. The unit cost of electricity depends to a large extent on the continuity of use, that is, the hours of operation per year. Rate schedule for Secondary Voltage Power in Barbados is shown in Appendix 2. Table 4.5 shows the electric power consumption for different gallons of water being pumped per minute at different heights in feet.

Table: 4.5 ELECTRIC POWER CONSUMPTION, KWH per hour

Lift (ft)	Gallons of water being pumped per minute									
	100	200	400	600	800	1000	2000	3000	4000	5000
50	1.5	3	6	9	12	15	30	44	59	74
100	3	6	12	18	24	30	59	89	118	148
200	6	12	24	35	47	59	117	177	236	296
300	9	18	36	53	71	89	178	268	356	445
400	12	24	47	71	94	118	236	354	472	590
500	15	30	59	89	118	148	296	444	590	-

SOURCE: WOODWARD,G. "Sprinkler Irrigation." Santa Monica, California. Sprinkler Irrigation Association. 1959.

2. The most important factors that affect the seasonal labour cost for applying water with sprinkler irrigation are:-

(a) Distance moved for each lateral setting. This cost varies considerably depending on the spacing arrangement, including the procedure developed for the type of equipment involved and the efficiency of both management and labour.

(b) Weight, length and size of lateral pipe.

(c) Manner of coupling and uncoupling pipe.

(d) Degree of co-ordination of irrigation labour and other farming operations.

(e) Manner in which the system is designed to fit the labour operations of the farm.

(f) The lay-out of the system.

The following table shows the labour requirement ranges for various sprinkler irrigation systems.

Table: 4·6 LABOUR REQUIREMENT RANGES FOR VARIOUS SPRINKLER IRRIGATION SYSTEMS

SYSTEM TYPE*	LABOUR (hrs/acre/irrigation)
Handmove	0.7 - 1.0
End-tow	0.2 - 0.4
Solid set (portable)	0.5 - 1.0
(permanent)	0.1 - 0.2
Side roll	0.3 - 0.6
Center-pivot	0.05- 0.3
Traveller	0.2 - 0.4

SOURCE: WOODWARD,G. "Sprinkler Irrigation." Santa Monica, California. Sprinkler Irrigation Association. 1959.

*See Appendix No.3

It has been estimated that the labour requirements for the application of 38 inches of water in zone 3 is in the order of 48 hour/acre/year and for the application of 50 inches of water in zone 4 is in the order of 63 hour/acre/year[1/] (see fig. 4.2 in Appendix No. 4).

C. MAINTENANCE COST FOR FARM SPRINKLER IRRIGATION SYSTEMS

1. Cost of maintenance for pumping equipment. This depends on the type power unit used and the manner in which it is operated. This cost includes lubrication and repairs. This should not exceed 10% per year of the original cost of the plant if the plant is driven by an electrical motor; for a gasoline engine assume 20% of the annual fuel cost and 40% of the annual fuel cost for a diesel engine.

2. Piping system maintenance and repair costs for sprinkler laterals and portable main lines, including valves are usually in the range of 2 to 7 percent of the original cost of the items per year. It will be lowest for hand-moved systems, when considerable care is used moving and storing the pipe.

3. Pumping plant attendance. This cost is negligible with plants driven by electric motors. Estimate 1 man - hour/day for internal combustion engines.

D. ANNUAL COSTS OF A SPRINKLER SYSTEM

The sum of the annual fixed and annual operating and maintenance costs gives the annual cost of owning and operating the sprinkler system.

[1/] HAGAND, A. "Farm Models For Production Diversification On Small Farms and Plantations." Ministry of Agriculture and Consumer Affairs, Barbados. 1977.

IV. COST OF IRRIGATION IN BARBADOS

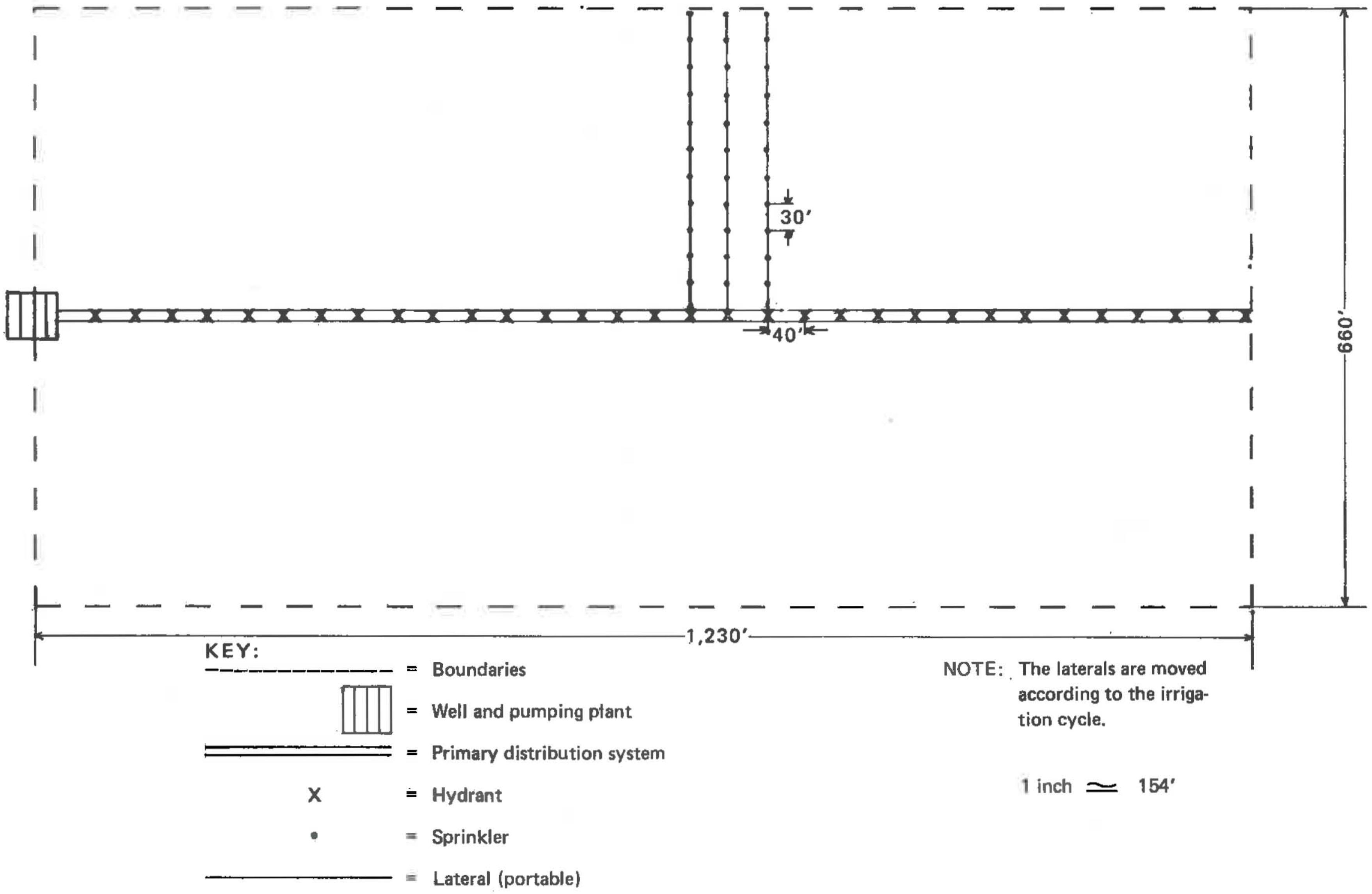
Tables 4.7 and 4.8 summarize the calculation of capital investment and annual costs of sprinkler irrigation for a 20 acre farm model in Barbados. This information is given as a guideline and is by no means conclusive.

The system design includes one well, one pump, buried 3' mains, and sprinkler equipment. The assumptions for the design are:-

- Working hours per day	15 hours
- Length of set	5 hours
- Irrigation cycle	7 days
- Gross application	2 inches
- Acres irrigation per set	1.0 acres
- Total acres	20 acres (1230' x 660')
- Spacing	30' x 40'
- No Laterals per set	3
- No Hydrants	31

FIGURE 4.1

DIAGRAM SHOWING A DESIGN FOR AN IRRIGATION LAYOUT FOR A 20 ACRE FARM



NOTE: The laterals are moved according to the irrigation cycle.

1 inch ≃ 154'

Table: 4.7. BARBADOS. CAPITAL INVESTMENT OF SPRINKLER IRRIGATION FOR A 20 ACRES FARM

EQUIPMENT	QUANTITY	INVESTMENT COST UNIT 1/ ($)	INVESTMENT COST ($)
a) Well 160ft, deep			22880
- Digging	160ft	132/ft	21120
- Adits & Materials	40ft	44/ft	1760
b) Pumping Plant 25HP, 160 Igpm 300ft TDH and Accessories			14760
c) Run electricity to pump	3 poles	2400/pole	7200
d) Distribution system			18271
- Hydrants	31	121	3751
- Pipes	1320ft	11/ft	14520
e) Surface equipment:			6522
- 2" x 30ft Lateral, riser & Sprinkler	33	194	6402
- Stop ends	4	30	120
f) Sub-total investment (a+b+c+d+e)			69633
g) Contingencies 10% of investment (10% of f)			6963
h) Total Capital Investment (f+g)			76596

Cost per acre: 76596 ÷ 20 = $3830/Acre

SOURCE: Barbados Rural Development Project. Cost Analysis of Delivering Water to Individual Farms. Sheet 75/85 and sheet 74 Mimeo.

1/ Current prices April 1980. Central Bank of Barbados, Economic and Financial Statistic. July, 1980 p 74-75.

Table: 4.8 BARBADOS ANNUAL COST OF SPRINKLER IRRIGATION FOR A 20 ACRES FARM

COMPONENT	INVESTMENT COST 1/	LIFE 2/ (Years)	CRF 3/	ANNUAL 4/ COST ($)	ANNUAL COST/ACRE ($)
A) Fixed costs.					
a) Well	22880	25	0.0782	1789	
b) Pumping Plant	14760	10	0.1359	2006	
c) Poles	7200	35	0.0690	497	
d) Distribution System	18271	35	0.0690	1260	
e) Surface Equipment				878	
- Sprinklers	6402	10	0.1359	870	
- Stop Ends	120	35	0.0690	8	
TOTAL FIXED COST (a+b+c+d+e)				6430	322
B) Operating and Maintenance Costs. 5/					
a) Labour 6/				3150	158
63/Hrs/Acre/Year x 20 Acres = 1260 hours					
1260h x$2.5/Hour =				3150	
b) Maintenance				1526	76
- Pump 7/				1200	
- Piping System 8/				326	
c) Power cost 9/				14868	743
- In Season					
Demand charge 10/ 25KVA x $4/KVA/Month = $100/month					
$100 x Month x 6 months =				600	
Energy Charge: 18KWH/h 11/ x 15h/day = 270KWH/day					
270KWH/day x 180 day = 48600					
48600KWH x $0.131/KWH =				6367	
Fuel Adjustment 12/ 48600 KWH x $0.13/KWH				6318	
- Out Season:					
Demand charge: 25KVA x $4/KVA/Month					
$100/Month, $100 x/Month x 6 months =				600	
Energy charge: 9/: 50KWH x 25KVA = 1250KWH					
1250KWH x $0.131/KWH = $163.75/Month x 6 months				983	
TOTAL OPERATING AND MAINTENANCE COST (a+b+c)				19631	977
C) Contingencies. 10% of Fixed Cost and Opertting and Maintenance Cost (10% of A + B)				2606	130
D) TOTAL ANNUAL COST (A+B+C)				28667	1429

NOTES:

1. See Table No 4.7.
2. Suggested depreciation period. See Table 4.2 for suggested depreciation periods.
3. Capital Recovery Factor (See Table 4.1). It is the figure corresponding to the selected interest rate (columns) and the expected number of years of useful life of the equipment (lines). It is assumed an interest of 6%.
4. The figure in CRF multilplied by the initial cost of equipment.
5. The system is designed to irrigate for 6 months of the year.

   180 days/7days/cycle = 25 irrigations (approx.)

   25 irrigations x 2" each/irrigation = 50" per year this is the amount of water required in Zone 4 Barbados according to Ministry of Agriculture and UNDP-FAO project report. (See Appendix No. 4).
6. Labour 63h/acre/year. For Zone 4 = 50"/Year. UNDP-FAO Project Bar 73/005 1977.
7. 10% of initial cost of the pump.
8. Assumed to be 5% of Surface Equipment Cost.
9. Secondary Voltage Power Rate. Season: 6 months. See Appendix 1.
10. 25Hp of electrical motor is approximately 25KVA.
11. See Table 4.5.Pumping Plant consumption for 160 US gpm and 300 TDH =18Kw/h
12. $0.13/KW. August 1980.

V. CONCLUSIONS

The capital investment for a 20 acre farm model in Barbados amounts to BDS$76596, being the estimated cost per acre at BDS$3830. The summary of the annual fixed and annual operating and maintenance costs given the annual cost of owning and operating the sprinkler system. The model used was 20 acres handmoved system, electrically powered and applying 50 inches of water per year to the crop. This showed the annual fixed cost was BDS$322 per acre and the annual operation and maintenance cost was BDS$977 per acre plus a BDS$130 per acre in contingencies for a total of BDS$1429 per acre.

REFERENCES

1. BARBADOS RURAL DEVELOPMENT PROJECT. Cost Analysis of Delivering Water to Individual Farms. Mimeo.

2. CENTRAL BANK OF BARBADOS. Economic and Financial Statistics. July,1980 p 89.

3. FOOD AND AGRICULTURE ORGANIZATION. Sprinkler Irrigation. Rome. FAO Agricultural Development Paper No. 88. 1968. p 152.

4. FRY,A.W. and GRAY,A. Sprinkler Irrigation Handbook, 10th Edition. California. Rain Bird Sprinkler, 1971. p 43.

5. MINISTRY OF AGRICULTURE AND CONSUMER AFFAIRS. "Farm Model for Production Diversification on Small, Medium and Large Farm in Barbados." Budgets for model Farming System, Supplement No. 2. Planning Unit-UNDP-FAO Project, Bar 73/005. 1977.

6. WOODWARD, G.O. Sprinkler Irrigation. Santa Monica, California. Sprinkler Irrigation Association. 1959.

Appendix No.1:

PROCEDURE FOR OBTAINING LOANS FOR IRRIGATION FROM THE AGRICULTURAL DIVISION OF THE BARBADOS NATIONAL BANK

WHO IS ELIGIBLE TO BORROW?

Small farmers and plantation owners.

HOW MUCH MAY I BORROW?

Anyone who fits into the above categories may borrow according to his agricultural needs.

WHAT CAN I DO?

First:- Go to the Agricultural Division at James Street, Bridgetown.

Second:- Ask to speak to the Credit Officer, Agricultural Bank Division and discuss with him your plans and ideas.

Third:- To qualify for financial assistance, you must simply satisfy the bank that you are genuinely involved in agriculture or, that there is a real market for product (s) in which you wish to invest.

Fourth:- You must satisfy the bank that you are capable of repaying the loan.

Fifth:- After discussions with the Credit Officer, during which he discovers where you need help, you will be given a form - application for loan - to fill out.

The specifications of an Irrigation loan are:-

1. Interest rates for irrigation are 6% payable from 3-7 years*
2- The bank lends up to $2,000 on securing (no collateral) ie. purely on the recommendation of prominent people.
3. Loans above $2,000 are secured by mortgage, chattel houses or real estate.
4. Terms of repayment are flexible and are usually arranged to suit the conditions of the loan, eg. repayment of a loan for cultivation of crops could be arranged so that a settlement is made after the crops have been reaped and sold

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*Current Interest rate by August, 1980.

SOURCE: BARBADOS NATIONAL BANK. "Services of the Commercial, Agricultural and Mortgage Finance Divisions." Creative Designs, Barbados 16p.

Appendix No. 2

RATE SCHEDULE

SECONDARY VOLTAGE POWER

WHO CAN APPLY?

This rate is available to all customers, (except street lighting),

SPECIFICATIONS OF SERVICE

1. Alternate current, 50 cycles, single phase or three phase at Standard Low Tension supply.
2. No service may be transmitted to other premises without the express consent of the company.
3. Terms of service may not be less than one (1) year.

WHAT ARE THE RATES?

Monthly rate.

(a) Demand charge for Company - owned transformers = $4.00 for KVA of Billing Demand.

(b) All energy - $0.131/KWH[1/]

(c) Energy charge - Subject to fuel clause adjustment.

NOTE: 1/ Current Rate by August 1980

SOURCE: The Barbados Light and Power Co. Ltd., "Rate Schedule S.V.P. Secondary Voltage Power." Pamphlet, Barbados. September, 1977

Appendix No. 2 cont'd.

WAHT IS THE MINIMUM BILL?

The minimum monthly bill shall be the appropriate demand charge plus the charge for the first 50KWH/KVA Billing Demand, which monthly bill shall not be less than the equivalent of a Billing Demand of 5 KVA plus 1,000 Kwhs of energy at the appropriate rate.

WHAT IS THE BILLING DEMAND RATE?

(a) Customers connected under this rate shall be metered as to demand and the Billing Demand shall be the maximum measured demand of the current month or the maximum measured demand of any of the previous 11 months; whichever is the greatest. The metered demand may be measured in either Kw or KVA at the option of the Company depending upon the character of the service. If the demand is measured in Kw then the maximum Kw reading shall be divided by a correction factor of 0.85 for conversion to KVA for billing purposes.

(b) The company shall reserve the right to assess the Billing Demand based on a connected load for installations including lifts and cranes, X-ray equipment and welders.

(c) For customers with a contracted demand, the billing demand shall be the higher of (a) or (b) or the contracted demand.

WHAT ARE THE RULES AND REGULATIONS?

Service under this schedule is subject to orders of the Public Utilities Board and to the currently effective "Information and Requirements Covering

Appendix No.2 cont'd

Installation of Electric Services and Meters." In any case of difference of interpretation between any provision of this schedule and said "Information and Requirements Covering Installation of Electric Services and Meters", the provision of this schedule shall be deemed to apply.

SOURCE: The Barbados Light & Power Co. Ltd., "Rate Schedule S.V.P. Secondary Voltage Power" Pamphlet. Barbados. September, 1977.

Appendix No. 3

TYPE OF SPRINKLER SYSTEMS

Sprinkler irrigation systems may be designated in several ways, they may refer to the type of pipe used, how it is installed, coupled and/or moved about, and the general operating procedure. There are permanent installations with buried main and lateral lines; semipermanent installations with fixed mainlines and portable laterals; and completely portable system with portable mainline and laterals.

HANDMOVE PORTABLE SYSTEM

A portable system is usually one with portable hand-move laterals, with portable mains, and sometimes with a portable pump. One more laterals may operate simultaneously, and when the irrigation in this position has been completed, the water is turned off and the lateral pipes are moved to other position. When irrigation of the entire field has been completed the laterals may be moved back to the first position of the same field or the entire system, including laterals, main and pumping plant, may be moved to another field, where the same procedure is followed

END TOW SYSTEM

This is a mechanically moved system. End tow systems are an aluminium lateral line mounted on either wheels or skids. The line is towed with a tractor from one set to another across a main line, and may be moved laterally also. The towed line can be connected to the main line from either end, thus requiring a buried main line at distances twice the length of the end tow line.

SOLID SET SYSTEM

A solid set system has enough portable laterals to eliminate being moved. The laterals are positioned in the field early in the season and remain until the last irrigation. The mains may be either buried or portable.

SIDE-ROLL SYSTEM

The side-roll wheel move is basically a lateral line of sprinklers suspended on a series of wheels. The Unit, stationary during sprinkler operation, is then shut off while being moved to each consecutive watering location. The unit is mechanically moved by an engine mounted at the center of the line, or an outside power source at one end of the line.

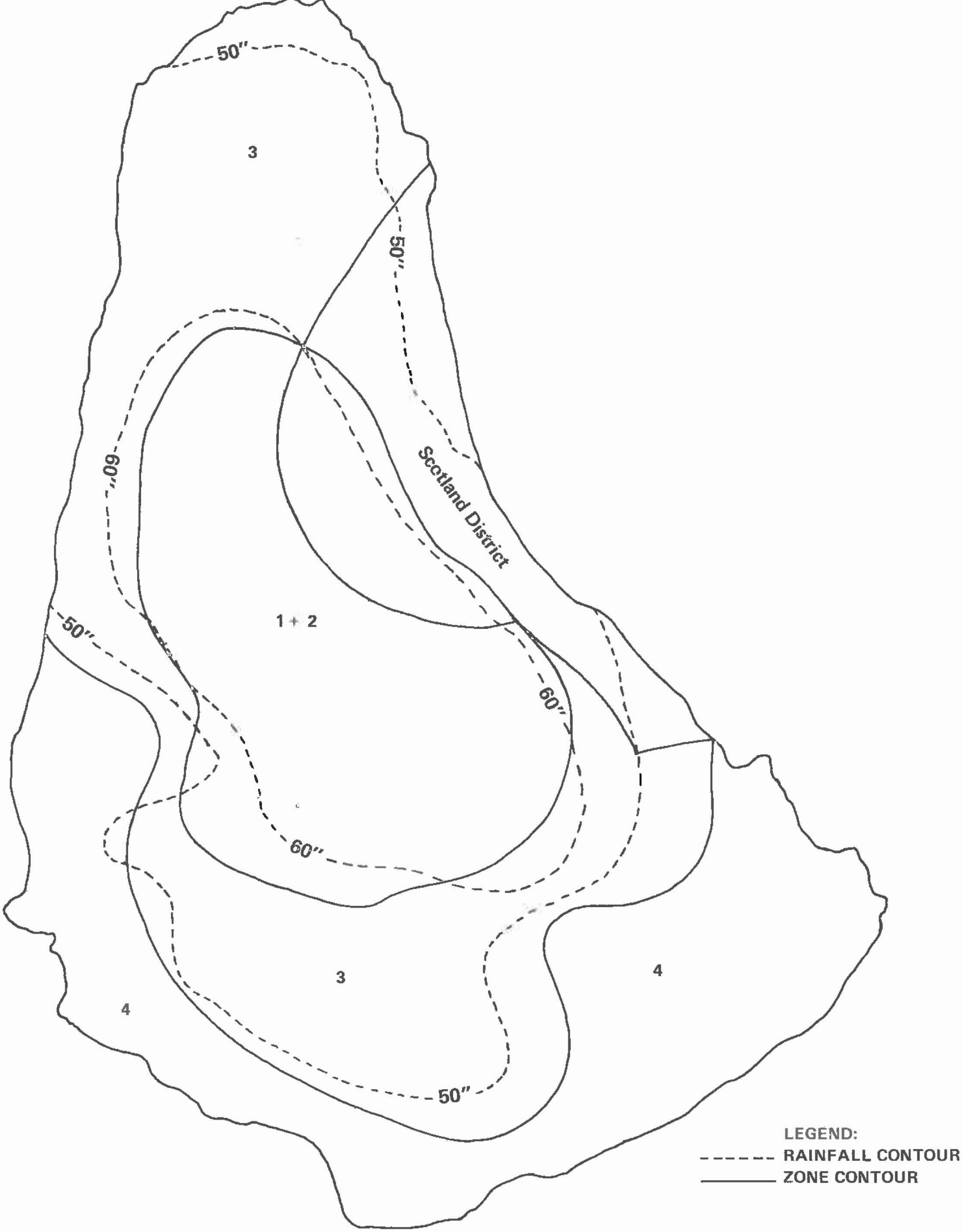
CENTER-PIVOT SYSTEM

The center-pivot system consists of a pipeline, various sized sprinkler heads spaced on it. The pipeline is suspended above ground on individually powered tower units. The system is self-propelled and continuously rotates around a pivot point at the center of the field.

TRAVELLING SPRINKLER (Traveller)

The travelling sprinkler consists of a single main gun sprinkler mounted on a portable, wheeled unit. The unit is initially positioned at one end of a travel path, connected to the end of flexible hose. It is then self-propelled until the end of the path before being stopped and repositioned in the adjacent travel path.

FIGURE 4.2
AGRICULTURAL ZONE MAP OF BARBADOS
APPENDIX 4



SOURCE: HAGAND, A. "Farm Models for Production Diversification on Small Farms and Plantations" Ministry of Agriculture and Consumer Affairs. Barbados. 1977.