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IRRIGATION



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MINISTRY OF AGRICULTURE AND FISHERIES

BULLETIN

No. 138

IRRIGATION

WITH NOTES ON CROPS
TO WHICH IT IS APPLICABLE



LONDON : HIS MAJESTY'S STATIONERY OFFICE

1947

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FOREWORD

THE unreliable nature of summer rainfall in this country has in recent years directed the attention of intensive cultivators to the means of controlling conditions by systems of irrigation. Although any system of this kind entails a heavy expenditure, independence of weather conditions confers a certain advantage and thus increases the possibility of planning crop production and labour distribution beforehand, besides effecting an improvement in the quality and quantity of the produce.

Responsibility for the information given in the Ministry's horticultural bulletins and leaflets has been taken over by the Specialist Advisers attached to the Provincial headquarters of the National Agricultural Advisory Service. These Specialists are formed into Groups, and each Group is in close touch with the appropriate industry and with the research work affecting that industry.

The Vegetable Group, which is responsible for the information contained in all bulletins and leaflets dealing with vegetable crops, is under the Chairmanship of Mr. F. A. Secrett, C.B.E., F.L.S., V.M.H. The members are Messrs. G. C. Johnson, C. E. Hudson, N.D.H., H. W. Abbiss, N.D.H., W. L. Steer, P. H. Brown, N.D.H., H. Fairbank, N.D.H. and A. D. Harrison, N.D.H.

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Ministry of Agriculture and Fisheries.

January, 1948.

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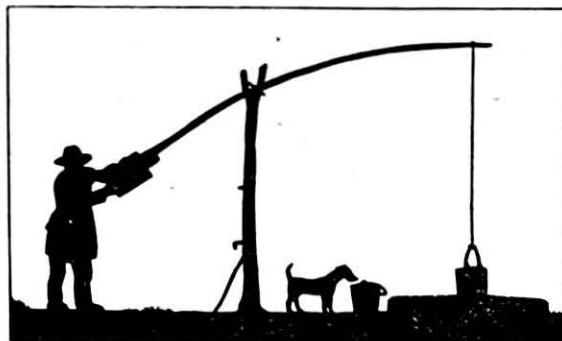
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IRRIGATION

WITH NOTES ON CROPS TO WHICH IT IS APPLICABLE

INTRODUCTION

Irrigation can be defined as the application of water to land by artificial means. Its purpose is to supply water to the land during periods of drought, so that necessary moisture may be always available for the growing crop: at times it may be used to facilitate the working of dry soils for the purposes of cultivation, seeding, etc. In this country, with its uncertain rainfall, there is occasionally too little water in the soil to maintain the proper growth of shallow-rooted vegetable crops, while at other periods the moisture may be excessive. It is true that periods of drought are seldom so prolonged here as in some other countries, but they often last long enough to check plant growth. The solution of the problem thus presented lies in the use of irrigation systems, and those which have been installed on intensively run vegetable farms in the south of England have fully justified their establishment.

Advantages of Irrigation. With an irrigation system water can be supplied to plants at any time; thus plant growth is unchecked during periods of drought and the crop reaches maturity earlier than it would under natural conditions. Vegetables and salads grown quickly on irrigated land are usually of excellent quality, the yields are higher and the spread of certain insect pests (e.g., flea beetles), which is often rapid under dry conditions, can frequently effectively be checked by irrigation. Moreover, irrigated land can be ploughed, cultivated and seeded at any time, and time is not wasted in waiting for suitable weather.

Disadvantages of Irrigation. Although far outweighed by the advantages, the disadvantages of irrigation are still very material. Irrigation water has been found to impair the texture of certain soils, which often deteriorate in consequence. The heavy crops grown on irrigated land use up the organic and inorganic plant foods and thus exhaust the fertility of the soils unless heavy dressings of dung and fertilizers are applied. Certain diseases and pests, e.g., the Club Root disease of brassicae, have been found to develop more rapidly, especially on soils that have been over-irrigated. Finally, the cost of installing the plant is substantial.

Systems. Where the area of land is very limited, water may be provided by means of a vessel carried by hand (e.g., a can), a method that has been employed throughout the ages. In more recent times hose pipes have been used to bring water from a distance to crops for which the watering can is inadequate. The hose is still widely used for watering plants that require individual attention and for supplying water to the soils in glasshouses. Having to be moved continuously, it requires constant attention and, even if employed on a small scale, occupies the time of at least one person and often two if the hose is of any considerable length. For centuries the system of applying water to crops through channels cut in the soil surface has been used, but its application is limited by the contour of the land; the need for economy in labour and more even and economical distribution of water has led to the introduction of mechanical apparatus for distributing it, the

best known forms being the spray line and the rotary sprinkler. These types distribute water over large areas as a finely divided spray.

Surface Irrigation. By this system water flows slowly and directly over the soil from an outlet situated at or very near soil level. There are several methods by which the water can be guided over the land to the crops, that by means of furrows being the most usual. Surface irrigation is used only to a small extent in this country, but in the United States of America and in Canada it is commonly employed to supply water to fruit and vegetable crops.

Spray Irrigation. This is the system most commonly used in England. The water, which must have an initial high pressure, is conveyed over the land in pipes: provided the pressure is sufficiently high, it may come direct from the town main. It is sprayed into the air and reaches the plants and soil in a finely dispersed form. As this system can be used on either undulating or level land, it has a decided advantage over other methods.

In the practical working of a spray-irrigation system having portable pipes or lines, the most expensive item is the moving of the lines. In America, where spray irrigation has been in use for many years, the spray lines are generally permanent, being directly supported by posts or slung from overhead wires connected with taller posts at wider intervals. These arrangements dispense with the labour and cost of transporting the lines, but necessitate a much greater length of lines, the supports for which may interfere with the cultivation of the land.

Sub-Irrigation is less common than the other two systems. Water is delivered below the surface soil through porous or ordinary drainage pipes whence it seeps through the soil and reaches the roots of the plants.

Chapter I. RAINFALL, WATER SUPPLIES, WELLS AND PUMPS

RAINFALL IN THE BRITISH ISLES

The need for irrigation in a particular district depends almost entirely on the summer rainfall in that district.

The average total rainfall in the British Isles in the years 1863-1935 amounted to 41.4 in. This would be ample for crop requirements if it were distributed more or less evenly throughout the year, but the months with the heaviest rainfall are often those during which little plant growth takes place out of doors, viz., October to January. The months during which rain is most needed for plant growth are May, June and July, and in some cases August also, and generally these months have a low rainfall, with the possible exception of August. In England, April is on an average the driest month and October the wettest.

The areas which approach the general average most closely are Ireland and the Isle of Man. In Scotland and Wales the annual rainfall slightly exceeds 50 in. The rainfall in England alone, amounts to 33 in. or about three quarters of the average for the whole area. The rainfall in the West is much greater than in the East, owing to the configuration of the land. The higher the altitude the greater is the rainfall, with certain exceptions.

A large proportion of central and eastern England has an annual rainfall of less than 30 in., and in many parts the annual total is less than 25 in.

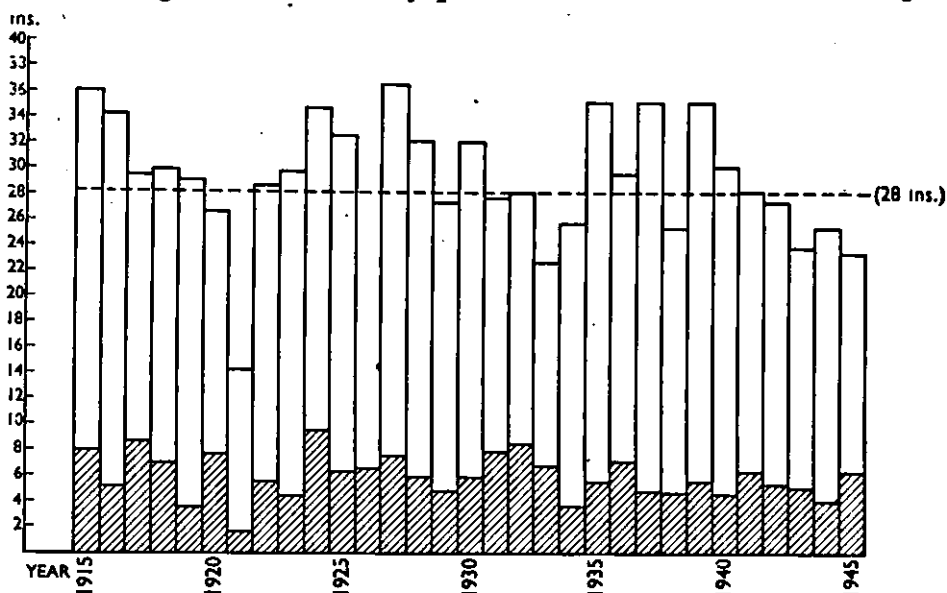


DIAGRAM 1. Annual rainfall in south-east England, 1915-45. Shaded portion = total fall in May, June and July. Unshaded portion = rainfall in remaining 9 months. Dotted line = average annual rainfall for the period 1881-1905.

There is a small area of about 50 sq. miles mainly on the Essex and Kent coasts adjoining the River Thames on which the average annual fall is less than 20 in. Areas of similarly low rainfall extend up the Essex and Suffolk coasts and into parts of Norfolk. Another area in which the fall barely exceeds 20 in. extends through the fens south of the Wash and is bordered by comparatively dry areas in Norfolk, Suffolk, Cambridgeshire, Bedfordshire, Huntingdonshire and Lincolnshire. The heavy and retentive nature of the soil in certain parts of these counties, however, largely counteracts the effect of the low rainfall.

In Surrey, Kent, Berkshire, Buckinghamshire, Worcestershire and the West Riding of Yorkshire, there are considerable areas on which the annual rainfall is between 20 and 25 in.

Fluctuations in Rainfall. In all districts the rainfall shows wide fluctuations from year to year, and the usually dry months may experience plenty of rain, or vice versa. The use that can be made of an irrigation plant may therefore vary substantially from season to season. In some seasons the need for the plant may be very limited, whereas in others it may be totally inadequate to cope with the demands made on it.

Diagram 1 shows the annual rainfall in S.E. England, and also the rainfall in May, June and July. It indicates that in that area,* in only six years did the May-July rainfall exceed a quarter of the annual total. In 17 seasons it was less than a fifth of the annual total, and in five of these it was less than one-seventh. In the drought season of 1921 it was less than one-eighth of the annual total, which itself was easily the lowest during the period covered. The diagram also shows at a glance the wide fluctuations in the annual and summer rainfall.

* Stations at Kew, Hastings, Marlborough and Southampton.

Diagram 2 shows the fluctuations of rainfall in each of the months May, June and July in the same area. It indicates that the June fall is well below the 1881-1905 average, compared with the July fall. Similar diagrams for eastern England* show a similar trend, but whereas the average May, June and July rainfall in S.E. England was slightly lower (5.8 in. compared with 6.2 in. in the East), the average total annual fall was higher (28 in. in the S.E. compared with 24 in. in the East).

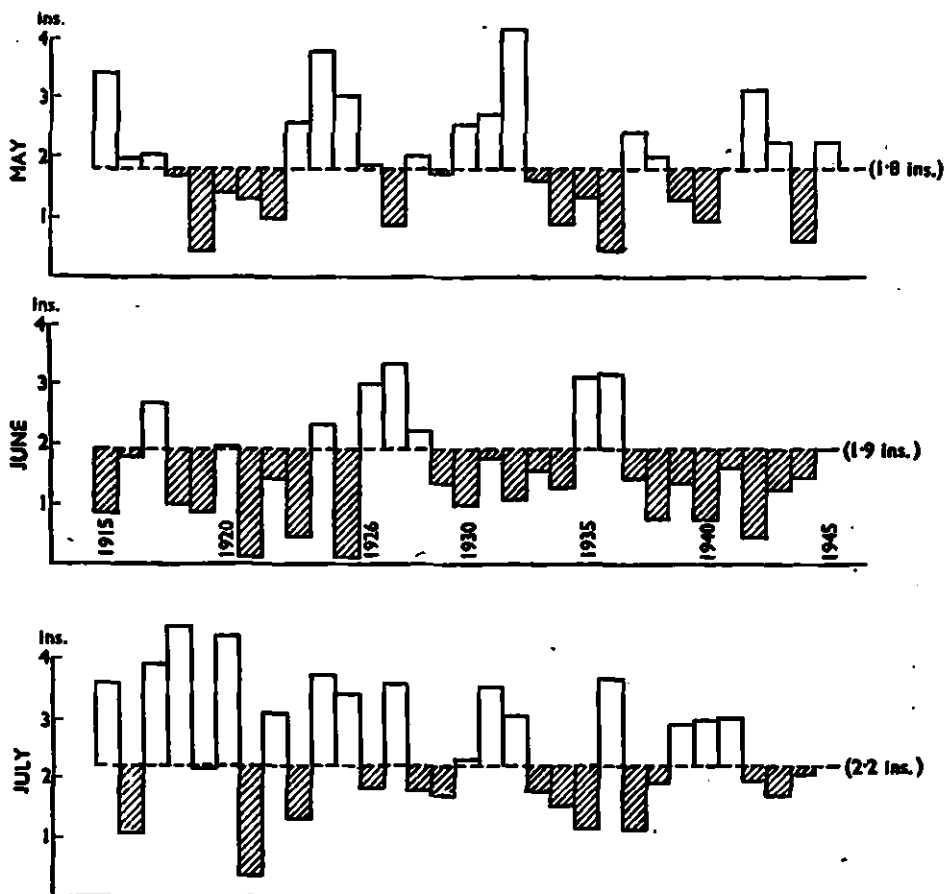


DIAGRAM 2. Fluctuations in rainfall in south-east England during May, June and July, 1915-45. Dotted line = averages based on period 1881-1905.

Table I (page 40) shows the rainfall for each of the months May to August at seven meteorological stations in S.E. England.

In 1921 the International Climatological Commission adopted the period 1881-1915 as the standard period for rainfall of the British Isles. As a result all the rainfall maps to date are based on that period. In 1934 the Commission recommended the adoption of the period 1901-1930 as the standard for computing climatological normals, and the monthly averages have now been computed for the latter period and expressed as a percentage of the corresponding value for the period 1881-1915(15†). An examination of these figures reveals that in certain months there were marked differences in the average rainfall in the two periods, and practically everywhere the rainfall of the 1901-1930 period exceeded that of the 1881-1915 period.

* Stations at Cambridge, Norwich, Shoeburyness, Rothamsted and Gorleston.

† References are listed on pp. 45-46.

WATER SUPPLIES

Under normal conditions, England is well supplied with water, which in most places is readily available for irrigation. The commonest source is the natural underground supply from which water can be drawn by means of wells or boreholes specially sunk for the purpose. River water is often more suitable for irrigation than that obtainable from wells, but rivers passing through industrial areas may contain effluent from chemical and other factories which is deleterious to plant growth. Brackish water is dangerous to crops and should be avoided.

Companies' Water. Water is often supplied by local companies at sufficiently high pressure to be used for spray irrigation purposes without an additional pumping plant. The total head (i.e., pressure) and supply must be carefully computed and the layout and length of spray line calculated accordingly, since it is inadvisable to use a great length of pipe line at too low pressure.

Well Water. Several considerations must be taken into account before the sinking of a well is undertaken. The geological structure of the area must be ascertained, since it will be necessary to sink the well into water-bearing strata. The geological data will give some guidance as to whether the well should be of large or small diameter, and whether shallow or deep.

Strata of permeable rocks consisting of such geological formations as New Red Sandstone, Oolitic, Cretaceous rocks and chalk, provide the main supplies of underground water in this country. The impermeable rocks are generally much older; the rain that falls on them does not sink into them but runs off in the form of streams. Thus a supply of water is generally available on such formations, provided a suitable reservoir or dam can be constructed. Impermeable rocks cover the greater part of northern England, Devon, Cornwall, Wales and Scotland. There are large belts of clay which also are impervious. District maps showing the contours of the water table are of great assistance in visualizing the flow of underground water, the position of springs and likely sites for wells, etc. Geological maps indicate the position of impermeable and permeable strata, from which it is possible to decide as to the advisability of sinking a well in a particular place.

In some areas where excessive demands on ground water are made, e.g., the Lea Valley, the capacity of the water basin has been seriously reduced at periods of maximum pumping during dry summers (e.g., 1944).

Regulations Concerning New Borings. The sinking of new wells or boreholes is now controlled by the Ministry of Health under the Water Act, 1945. The Underground Water (Controlled Areas) Regulations, dated May 11, 1946, made under Section 14 of the Water Act, state that if a person wishes to sink a well, he must obtain from the Minister of Health a licence before he can commence the work. The application for a licence must be accompanied by an Ordnance Survey map showing the situation and the surrounding district within a radius of at least a mile, on a scale not less than six inches to one mile. He must also state the purpose for which he wants the water, and whether he wishes to make a trial bore, a new borehole or well, or extend existing works, and must give details of depth, size, lining, rate of pumping, etc. Details of the geological strata from which the water is to be drawn, and through which the proposed well or borehole is expected to pass, must also be provided.

Permeable Strata. The strata considered to be permeable for all practical purposes comprise five principal groups:

(1) **THE CARBONIFEROUS**, comprising the carboniferous limestone and shales, the Millstone grits and shales, the Coal Measures with associated shales, fireclays, grits, etc. Only a relatively small quantity of underground water is obtained from these measures.

(2) **BUNTER AND KEUPER SANDSTONES.** Large quantities of water are obtained from the outcrop of these rocks which extend over 1,750 square miles in Cheshire, west and south Lancashire, the valleys of the Yorkshire Ouse, the Tees and the Trent and in Warwickshire, Leicestershire and Nottinghamshire, and in Somerset and Dorset.

The Bunter Sandstones are subdivided into three, of which the Bunter Pebble beds yield the largest quantity of water. The deposit of these in Leicestershire and Warwickshire is under 200 ft. thick, in Staffordshire 200-300 ft. and in Lancashire up to 500 ft.

(3) **THE OOLITES.** These are limestones and sands extending from Dorset to Yorkshire. They are subdivided into (a) the Upper, including the Portland Stone and Purbeck beds; (b) the Middle, including the Coraleian, which supply water in limited quantities; and (c) the Lower Oolites, which are the most prolific sources of supply.

The Oolites constitute a valuable source of water, the chief areas being the Northampton sands, the Lincolnshire limestone, and the Cotswold sands of Gloucestershire and the Midford sands of Somerset. The uncovered Oolites amount to 2,500 square miles, and there are an additional 1,000 square miles underlying other permeable rock. When, however, the Oolites are covered by thick strata of boulder clay, as in North Yorkshire, they are of little use as a source of water.

(4) **THE UPPER AND LOWER GREENSANDS.** The Upper Greensand underlies chalk and overlies Gault. It is of less importance than the Lower Greensand, of which there are extensive outcrops in the counties of Bucks, Beds, Hants, Kent and Sussex. Large areas of Lower Greensand occur underground.

(5) **THE CHALK.** The chalk constitutes the most important source of water in England. The chalk formation has been divided into three main divisions: the Upper, Middle and Lower. The lower chalk is of a marly nature and is not such a useful source of water as the other divisions. Much water is obtained from the chalk in the Home Counties, Dorset, Hants, Sussex and Kent, the London basin (Fig. 1) (where clay overlies the chalk stratum) Yorkshire, Lincolnshire and East Anglia, where some parts of the chalk are covered by impermeable clay and others by permeable water-bearing formations.

The upper chalk extends to a maximum depth of 1,000 ft., the middle chalk varying from 100 to 200 ft. in thickness.

Water "Divining" or "Dowsing". This is the term given to the method by which certain persons claim that they can discover the presence of underground water by the reactions of a hazel twig or metal rod. The rod, about 2 ft. in length, is held in both hands whilst the diviner walks over the ground

and it is stated that when he passes over the source of water a movement of the rod takes place. Some affirm that divining is only of use in relation to running water which is not deeper than 32 ft. and can be dealt with by a surface pump, but instances are numerous in which diviners have located deep-seated supplies. Under certain conditions the diviner's rod may respond to water up to 300 ft. deep.

Much has been written on this very controversial subject, but there is still no satisfactory explanation of the phenomenon. Where special tests have been set for diviners the results at times have been far from convincing. Small streams of water are comparatively common in permeable strata and the diviner can be reasonably sure of finding some of these; at any rate, diviners often locate such spots where subsequently wells are sunk and reach water.

WELLS

Wells are generally described as of two kinds, viz., surface and deep wells. Surface wells are confined to the subsoil and seldom exceed a depth of 50 ft. Deep wells penetrate the subsoil and the impermeable strata and reach the permeable stratum below (see Diagram 3).

Shallow or Dug Wells. Shallow wells—as distinct from boreholes (*see* below)—may have a diameter of 3-12 ft. or more, and their depth varies considerably from district to district according to the depth of permeable subsoils above the impermeable stratum. This type of well is most useful in strata which permit a slow passage of water. In estimating the size and depth of a dug well, it is advisable to allow a margin above the calculated capacity, but the margin should be kept within reasonable limits. Many wells have been sunk with the object of obtaining a required supply of water at a certain cost, only for it to be found that the capacity of the well has been far in excess of requirements, so that the first cost has been unnecessarily high; such errors are usually due to a miscalculation as to the porosity of the water-bearing stratum.

Although many surface wells are lined with impervious materials and the upper part constructed in such a manner as to prevent the entry of water that has not been properly filtered, such a precaution is seldom necessary where the water is required solely for irrigation purposes.

A common form of surface well of cheap construction is known as the "curb well". This is constructed by first removing the soil to make a cylindrical cavity about 8 ft. in diameter and 4 ft. deep. A wooden "curb", made of staves 3-5 in. apart and held in place by rings of wood, is then fitted into the excavation and loose bricks are placed on the curb against the side of the well. As soil from the bottom is removed, so the curb is forced down by the weight of bricks which are continually being built up on it.

Impervious linings for shallow wells consist of segmented plates, bolted together as a cylinder; they may be of cast iron, mild steel or, occasionally, concrete.

Deep Wells or Boreholes. A borehole is simply a narrow cavity—anything from 4 to 18 in. in diameter—drilled into the soil from the surface or from the bottom of a shallow well. When necessary it is lined with metal tubes as boring proceeds. Depths vary greatly, sometimes exceeding 1,000 ft.

Boreholes, owing to their small area in the water-bearing stratum, are suitable in strata which allow rapid movement of water. If sunk into strata of low permeability, or if they are too narrow, they present too small an area in the stratum, with the result that sand or other material is drawn in

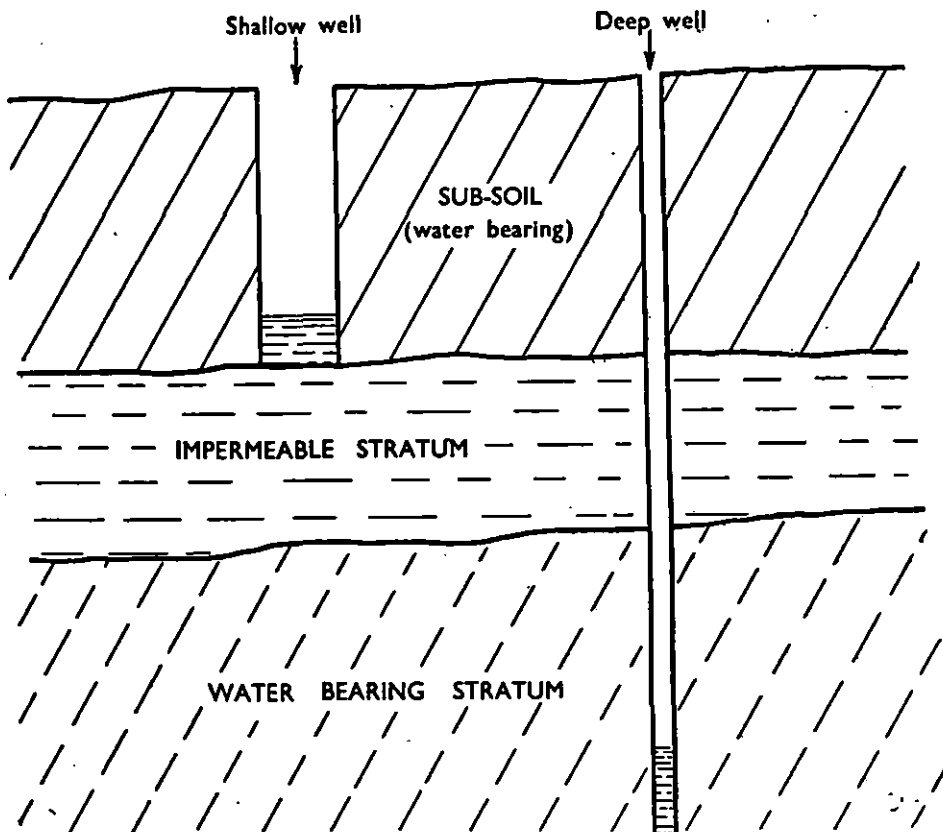


DIAGRAM 3. Shallow well and deep well.

and the level of water may be so lowered that pumping becomes uneconomical. Special machinery is needed for the construction of boreholes, but they have advantages over dug wells in that under suitable conditions they can be put down in a shorter time, and that they can easily be protected from contamination by shallow or surface waters.

Artesian Wells. Artesian wells are, in effect, boreholes sunk into a water-bearing permeable stratum lying between two impermeable strata, and are so formed that the level of water in the permeable stratum actually rises above the soil level of the inner impermeable stratum. The permeable stratum appears as an outcrop generally on the side of a valley. When the inner impermeable stratum is pierced, the water rises by hydrostatic pressure to its next level which in the case of the "true" artesian wells is at or above ground surface.

The Abyssinian (Driven Tube) Well. This is a simple and cheap form of well suitable for providing a limited supply of water from a water-bearing stratum which is near the surface. It consists of a number of steel tubes 2 in. in diameter screwed together, the lowest section being provided with a specially shaped point of solid steel for piercing the soil stratum

under force. About 18 in. of the section immediately above the point is perforated to allow for the infiltration of water. The tube is driven into the ground by a large weight or "monkey", which is manipulated by ropes and pulleys; the percussive action of the monkey on to a drive block at the top of the tube enables the tube to be driven into the ground. As driving proceeds, so new lengths of tube are screwed to those already in the soil until the water is reached. If the water is not reached within about 25 ft. the tube can be removed and inserted elsewhere. As ordinary suction pumps are used the water level should not be deeper than about 25 ft., although the tubes may extend further. During the first pumping the water may be dirty, but it clears as pumping continues. Where the flow of water into the tube is insufficient for the grower's needs, a second or third tube may be sunk some distance away and linked up with the first. In this way sufficient water may be available to irrigate a considerable area of land. For this type of well an open soil such as coarse sand or gravel gives better results than fine-textured soils. Tube wells are inoperative in clay soils.

Capacity and Yield of Wells. The capacity of a well depends on a number of factors, the chief of which is the size of the cracks and fissures in the stratum. Chalk rock itself is impermeable, the water being contained in and flowing through, the fissures in the rock. Other factors are the head of water under which the flow occurs, the size and shape of the well and the character of the walls and casing. Thus the size of the fissures not only fixes the rate at which water can penetrate to the well, but it also determines the proportion of contained water that will be given up (48). Where a water bearing stratum is fine-grained or contains only small fissures the rate of flow of water is very slow, and the best result is obtained with a dug well of large diameter, since the infiltration and the storage capacity are large. An increase in the diameter of a deep well has little effect on the total yield of water, for doubling the diameter of 6-12 in. wells may add barely 10 per cent to the theoretical yield. With shallow wells, however, the yield seems to be proportional to the diameter when the well is being drawn upon to its full capacity.

The flow of water into deep wells usually varies proportionately as the water level in the well is lowered by pumping. The result of removing a large quantity of water from a well in strata other than those that are very porous is to lower the water table in the vicinity so that it assumes the shape of a vortex, which is often called a "cone of depression" or the "circle of influence" of the well. During pumping, the water level is naturally lowest at the well, gradually rising as the distance from the well increases until at some distant point the normal level is reached. As the pumping continues the level is lowered more and more until finally the water flows into the well as fast as it is pumped out, a stage at which no further change in the level occurs. This is known as the pumping water level. After pumping ceases the water will again resume its normal or static level.

The yield is adversely affected if the well is silted up or clogged with debris, or if the lining is in need of repair. Similarly, the screen of a deep well may be blocked by a deposit of sand, silt, etc. To avoid this it is advisable not to over-pump the well.

The probable yield of a dug well can often be estimated by the quantity of water pumped during the sinking of the well. It is difficult to test

accurately the probable capacity of a borehole during drilling, and the best plan is to test it directly after drilling by pumping for a period to ascertain the output and the extent to which the level of the water will fall so that the pump can be placed sufficiently low. Where, however, the ground water has only a very slight slope the yield decreases very gradually and a very long period of pumping may be necessary to bring the conditions to a final state of equilibrium. Theoretically the water level should not be more than 32 ft. below the pump, but in practice it should not be more than 24-26 ft. Many wells sunk in valley gravels to a depth of 18 to 26 ft. provide unlimited supplies and in such instances the pump can be installed at ground level.

Temperature of Water. When the water is supplied by a shallow well, its temperature is seldom very different from the night-air temperature, but deep-well water is generally rather cold (usually about 50-54°F.), and the temperature should therefore be raised before the water is applied to growing crops.

There is no definite ruling as to the ideal temperature of the water which is to be applied to any particular plant. As a general rule, it should approximate as closely as possible to the optimum air temperature for the healthy development of that plant. Although in practice this ideal is impossible to attain—indeed under outdoor conditions few crops are subjected to optimum conditions for the greater proportion of their life in the English summer—yet for the best results the difference between the air temperature and the water temperature at the time of irrigation should not be very large.

The effect of applying cold water by flood irrigation to a growing plant is to check its growth owing to the cooling of the soil, with consequent inhibition of healthy root action and the vital soil processes. Normal growth is therefore not resumed until the soil temperature is raised again, which in early summer may take several days. This loss of a few days is not the only drawback, however, for once there has been a check in the growth of some plants, e.g., cauliflowers, chrysanthemums, the development of the plant is upset and final results are unsatisfactory. As the crop may require two or three applications of water, the combined effect of these temporary setbacks would counteract, to some extent, the advantages due to watering. The crop can be matured and marketed more quickly if it is encouraged to grow naturally and quickly by applying water at the correct temperature. Conversely it is of little use and often detrimental to the plant to apply irrigation until the soil has warmed up in the spring, but usually it is unnecessary to irrigate until the soil becomes warm. Droughts such as were experienced in the spring of 1938 are abnormal: then the soil temperature was low, the drought was prolonged, and where water was applied no improvement of the crop was visible.

Method of Raising the Temperature of the Water. Where the water is pumped into a storage tank before distribution, the temperature of the water can be raised by running through it a length of piping which is connected to a boiler outside the tank. Where a storage tank is not used it is possible to raise the water temperature by running the delivery pipe through a length of larger pipe (18 to 30 ft. depending on its temperature) through which hot water circulates. This method is often employed in glasshouses where the ordinary 4 in. heating (flow) pipe is used for the purpose. Other methods of

heating glasshouse water supplies are either to erect the water tank inside the house, when the air temperature will raise that of the water, if given adequate time; or to pass steam through the water in the tank (in this case, usually outside the house)—a useful method where steam or steam-cum-water heating is used. If electricity is available, immersion heaters, thermostatically controlled, might be used.

Hardness of Water. Generally the softer the water the better it is for the growing plant, provided of course the land is not acid in reaction; in the latter condition a water with a high lime content is better, especially where lime-loving plants are grown. Water with a high lime content leaves a deposit on the leaves, fruit and flowers of the plant and thus detracts from the value of the product. It must be admitted, however, that in this country no cases on record have shown any appreciable difference between the effects of hard and soft water on crop yields.

PUMPING SYSTEMS

When water from a public supply is not used, some machinery must be used for pumping the water from its source to the land to be irrigated, and in the case of spray irrigation to create a pressure sufficiently high to distribute the water in a spray similar to gentle rain.

There are three types of pump suitable for deep wells commonly used for supplying water to irrigation systems, viz., the centrifugal pump, the piston pump and the air-lift pump. While all three are suitable for pumping water from the well only, the air-lift pump cannot be used for distributing the water under high pressure, but it is very useful for pumping the water to a surface reservoir.

Before describing the pumps, it is necessary to emphasize that the pump used for raising water from the well is not always used for driving the water through the irrigation system; a second pump may be used for this, and where an air-lift is used, this second pump is essential. Irrigation systems, in which the pressure has to be generated may, therefore, be divided into (1) those in which only one pump is used, and (2) those in which a pump is used for raising the water from the well to a reservoir and a separate pump to distribute the water over the fields. In system (1), the pump lifts the water from the well and distributes it through the pipe system under pressure. The pump can only be placed within about 28 ft. of the water level and, therefore, if the pump is to be on the soil surface, the water supply must not be more than about 28 ft. below the soil level, i.e., a stream, pond or shallow well—the theoretical distance is 32 ft., but to allow for low atmospheric pressure, 15 ft. is a safe maximum distance. If the water level is deeper than this, the pump must be placed inside the well so that the distance between it and the water, when at its lowest level, is never greater than 15 ft. System (2), in which the pump used for raising the water from the well is separate from that used for distributing the water, is often employed where the water supply is too deep to render the use of a high pressure pump economical. An air-lift is sometimes used for this purpose, although deep-well piston and special centrifugal pumps can also be used. The water is run into a tank from which a high pressure booster pump, generally of the centrifugal type, distributes the water through the pipe system.

The Centrifugal Pump. This pump is suitable provided the water supply is comparatively near the soil surface (Figs. 2 and 6).

There are two types of centrifugal pumps; (a) the turbine pump, and (b) the volute pump. The impeller consists of a series of curved blades attached to a rotary shaft. The turbine pump maintains a higher pressure, but it is correspondingly more expensive. A centrifugal pump with a single impeller is known as a single-stage pump; one with two impellers, as a two-stage pump, and so on, the more powerful pumps being provided with six or more impellers. When running at a moderate speed the single-stage pump with open impeller is usually capable of raising water through a total head of about 40 ft. If more impellers are added and the number of revolutions remain the same, the lift is increased. A high lift can be obtained from a single-stage pump if it is run at high speed, but the cost is greater and it requires more attention than the slower running pump.

Centrifugal pumps should be set as near to the water level as possible. Their efficiency is greatly reduced, or they will cease to pump water, when only a small amount of air is allowed to enter.

Pumps of this type should be used only when the pressure required will be well within the limit laid down by the makers. Centrifugal pumps work most efficiently at those lifts for which they are specially designed. If run against a total head which differs even only slightly from that limit, their efficiency is decreased considerably. Choice of the right pump is, therefore, very important and makers should be given full details of the irrigation system so that the total head can be accurately estimated.

Submersible pumps, combining a centrifugal pump and electric motor as a single unit are obtainable, and these can be used below water level, the power unit and cable being adequately protected from the water.

Piston Pumps. Piston pumps can be used for the smaller irrigation systems, where a comparatively small water output is required. The majority of these pumps are designed to run at about 40 revolutions per minute, under pressure of 40-45 lb. per square inch, but if the pressure is raised, the speed of the pump must be reduced. The capacity of piston pumps used for irrigation purposes seldom exceeds 100 gal. per minute. Pumps with small pistons working at high speed are designed for pressures up to 100 lb. per sq. in.

The pumps are fitted with one, two or three cylinders, the single cylinder models being used for small irrigation plants only. A double acting pump reduces pulsation in the pipe lines and ensures a steadier flow of water, but an air chamber must be provided on the outlet. Piston pumps require a minimum of attention and, if properly installed, will require no priming. If, however, the head of water falls below the pipe opening and air is admitted, priming will be necessary before the pump will pick up its suction.

Where the water level lies below the suction depth, either the entire pump must be placed in a pit dug to the necessary depth, or the cylinder must be placed at this depth in a well casing or pit, and the pistons driven from ground level by long rods. This type, called a deep-well pump, is more expensive than the first-mentioned type.

Apart from its small output the main drawback of this type of pump for irrigation purposes is the danger arising from the possible closing of outlet valves in the field pipes whilst the pump is working. If this happens, the

pump will almost certainly be partly fractured. The other types of pumps are comparatively fool-proof.

Air-lift Pumps. Air-lift pumps are preferable where the water is dirty (i.e., containing sand, grit, etc.), or in need of aeration, and where pumping is required to be done from scattered wells (Figs. 4 and 5).

The life of air-lift pumps is considerably longer than that of other types of pump owing to the fact that the water does not come in contact with moving parts. All working parts are above ground surface and the power plant can be situated at any reasonable distance from the well. Fig. 4 illustrates the working of a typical air-lift installation.

The equipment consists of a power unit driving an air compressor (E), which is connected to an air receiver (D), which stabilizes the pressure. An air main (B) conducts the compressed air from the receiver to the foot piece (C), which is situated near the bottom of the well. The foot piece consists of an ejector perforated with small holes, through which the air is forced into the space between the ejector and the outer shell of the pump. The mixture of air and water flows upwards through a discharge pipe or rising main (A) to a delivery tank situated near the head of the well.

The principle of the air lift is based on the fact that in the mixing of air and water, the density of the water in the discharge pipe becomes lower than that of the water outside the rising main, with the result that it flows upwards. The velocity of the upward flow depends on the depth below the pumping water level at which the air ejector is submerged.

To prevent oil from the compressor becoming mixed with the water, it is necessary to provide an oil filter and this is placed at the highest point in the air line. When the pump is running at full capacity, the filter may require to be emptied twice daily. The provision of a "breathing hole" in the air line also allows for the escape of oil and air-lifts fitted with it are claimed to be more efficient.

To prevent overheating of the receiver, a useful safety precaution is to fix a release cap in the outlet pipe. This contains a metal of low melting point, so that if the receiver overheats this metal will melt and the compressed air will be released.

A separate pump, called a "booster pump," distributes the water from the reservoir through the irrigation pump system. By using a reservoir, the water can be properly conditioned, including aeration, before it is applied to the crop.

THE RESERVOIR. In spite of the design of air-lift pumps, the pumping up of a certain amount of sediment from the well cannot be avoided. It is advisable therefore to build a partition in the surface tank, to enclose a separate chamber, where impurities can settle. The clean water can flow through a "V" notch in the top of the partition into the main part of the reservoir. As an additional precaution, the take-off pipe in the reservoir should be well protected by gauze. To allow sand to get into the system leads to serious wear of the booster pump and blocking of the nozzles causes much waste of labour (see Fig. 9 for view of reservoir).

Capacity of the Pump. Pumps used for irrigation usually have an output varying between 30-250 gal. per minute. The figure of 30 gal. is generally

considered a minimum for commercial irrigation purposes, but pumps delivering smaller quantities are made for use with irrigation systems in private gardens, etc.

POWER SUPPLY FOR PUMPING

An electric motor or internal combustion engine may be used for driving the pump (Figs. 2, 3 and 6).

Before purchasing a power unit, it is essential to calculate the power required for supplying water at the required rate of flow and pressure, and then to select the power unit that is capable of providing this.

For spray irrigation, the unit must be capable of driving the pump when the total pressure or head on the pump is at its maximum. This head is called the maximum load. To allow for wear and tear, etc., it is advisable to choose a unit with power slightly in excess of the amount that will be needed.

Where a direct drive is not used, "V" belts are preferable to flat belts.

Electric Motors. Electric motors are very convenient for pumping and their use may be recommended provided the cost of the electricity is sufficiently low for them to be run economically. They are suitable for driving all sizes of pumps, are practically noiseless and require very little attention. The initial cost of a motor for this type of work is less than that for an internal combustion engine of corresponding power, but the cost of running is generally greater. The extra cost, however, is counterbalanced by their simplicity and quietness of running. In fact they can be regarded as comparatively fool-proof. All insulations should be moisture resistant and care should be taken that no moisture can get into the motor. This can be overcome by housing the electric motor in a heated building, but failing this, the motor should be run for a short period about once weekly in order to keep it thoroughly dry, provided of course that it is not a direct drive. When the water supply is some distance from the power line, the cost of service wires is often the limiting factor in deciding whether electricity should be used, but the more uses to which electricity can be put on the farm, the cheaper the rate.

For night running of plants where a collecting tank is used, the booster pump can be automatically switched off when the tank is empty by installing a float switch in a water-tight cylinder at the bottom of the tank. Similarly, when filling the tank the well pump can be automatically switched off when the tank is full by installing another float switch at the top of the tank.

Internal Combustion Engines. There are numerous makes of internal combustion engines with either vertical or horizontal cylinders, but they are all suitable for irrigation purposes. A number of very satisfactory pumping outfits, with engine and pump combined as a single unit, is available. Diesel engines give the least trouble and are cheaper to run than petrol engines.

Windmills. Windmills pump comparatively small quantities of water (about 50 gal. per minute) and owing to the uncertainty of their running, and the fact that the total lift seldom exceeds 50 ft., they are not suitable for direct irrigation. They are suitable for pumping water into a surface reservoir, from which it can be distributed by another pump at the required pressure.

Use of Hoses with Power-driven Pumps. Where a hose is used to convey water from a power driven pump, it is important to ensure that no kinks are present in the hose; otherwise considerable damage to the pump or hose and connexions may result.

Rules to Observe in the Management of a Pump

1. No pump should be started or run "dry". If delivery fails, shut off the power supply and investigate.
2. Do not tighten up the pump glands indiscriminately. If the glands require to be tightened up hard to stop "weeping" or leakage, re-packing is required. Tight glands take much power and cause heating and scoring of pump shafts and bearings. A small amount of leakage is preferable to frequent tightening and repacking of glands.
3. Attend to all lubrication points carefully, using grease for grease lubricated points and oil for oilers. The manufacturers or oil companies will always be pleased to recommend suitable oils and greases.
4. See that the correct valves and cocks are open before starting up.
5. Run the pump at the speed for which it is designed.
6. It is important that the whole system should be capable of thorough draining, and all pumps should be provided with a base plug for draining the water from them.

AERATION OF WATER

This is a somewhat controversial matter, but some authorities claim that to obtain the best results, water used for irrigation purposes should be aerated. The water from rivers and ponds is generally well aerated, but water from deep wells contains very little air and in such cases it has been found worth while, with certain irrigation plants, to install an aeration apparatus, particularly in installations where the water is supplied under low pressure. Where it is supplied under high pressure at the nozzle line, the water is thrown high in the air and divided into a spray, sufficiently fine to enable it to become reasonably well aerated before it descends on to the plants. Similarly, when an air-lift pump is used to pump water from the well, the water is aerated sufficiently during the pumping process and no further aeration is necessary. The beneficial effect of aeration in spray irrigation may easily be due to an increase in temperature of the water by the time it reaches the soil. Spray irrigation affects the soil temperature far less than flood irrigation, owing to the smaller amount of water applied and the longer time of application. Spray irrigation will cool the leaves for the period of application but will barely affect the root temperature.

The equipment for aerating water consists of a motor-driven compressor; usually the motor used for driving the pump is used. The compressed air is driven through a diffuser into the water.

It is considered by some growers that the foliage of plants is not so liable to be scorched by aerated water, whereas scorching often results from the use of other waters.

Addition of Chemicals to Water. It is possible to add small quantities of a concentrated nutrient solution to the irrigation water, a practice sometimes referred to as "solutionizing". A special apparatus situated in, or adjoining,

the pumping house is necessary and by adjusting stop cocks, the quantity and concentration of the nutrient solution entering the irrigation pipe can be regulated.

By using apparatus called a hydrostat chemical injection unit, which is driven by tapping a small amount of water power from the delivery pipe, it is possible with the help of a graduated scale, to apply nutrient solutions to the plants in widely varying proportions (see Fig. 8). Potassium nitrate has given good results but vegetable crops do not respond to the addition of phosphates so readily.

It is claimed that water containing these small quantities of mineral nutrient increases crop growth and yield and that when combined with aeration, irrigation can be carried out in hot sunny weather without much fear of damage to the crops by leaf scorch.

The application of soluble plant foods by this method has great possibilities because, apart from the fact that the food becomes immediately available to the plant, losses due to leaching in the periods of heavy rainfall are reduced to a minimum. In practice, therefore, smaller quantities of fertilizers are required per unit area than are required under ordinary conditions.

PRESSURE OF WATER

Calculation of Head. The pressure of water is generally stated in feet of head or lift, this being the height of water required to cause that pressure. A pressure of 1 lb. per sq. in. is practically equivalent to a head of water of $2\frac{1}{2}$ ft. When water is passing through the system, the friction set up decreases the water pressure on the nozzles which, accordingly, has to be allowed for in computing the total head. The pressure required for spray systems is kinetic, not static pressure, i.e., it must be maintained in the pipe while spraying is in progress.

The total head of water on the working pump consists, therefore, of the pressure required (1) to lift the water from the source of supply to the pump inlet and for this the number of feet of head is the vertical distance between the pump inlet and the lowest level of water in the well or from whichever point the water is obtained (this is the static suction head); (2) to lift the water from the pump to the highest stand pipe (this is the vertical distance between those two points and is called the static pressure head); (3) to overcome friction set up by the water being forced through the pipes (see Table IV: Friction Head), and (4) to throw the water from the nozzles in a jet to the required height (Pressure Head). In estimating the total lift, allowance must also be made for any lowering of the level of water at the source, and the figure for (1) should always be based on the lowest level.

The suction lift and the friction head in the suction pipe together should, for safety purposes, not exceed 25 ft. To allow for eventualities and loss of efficiency in the pump, it is advisable to allow for a total head of about 30 ft. in the suction pipe.

The friction head in the pipe lines depends upon the size and length of the pipes and the quantity of water they carry. For short spray lines up to a distance of 50 ft. apart, the pressure at the commencement of each should not be less than 20 lb. per square inch (47 ft. head). The ideal working pressure at this point for 200-ft. spray lines is 50 lb. per sq. in. but some

commercial systems are designed for a pressure at the stand-pipe of 80 lb. per sq. in. (i.e., 185-ft. head).

The horse power output of the motor is roughly calculated by multiplying the total head in feet by the number of gallons pumped per minute and dividing by 3,300, i.e., $\frac{\text{G.P.M.} \times \text{H.}}{3,300}$. The figure of 3,300 is arrived at by dividing 33,000 (the number of foot pounds in 1 horse power) by 10 (1 gal. of water weighs approximately 10 lb.). The formula $\frac{\text{G.P.M.} \times \text{H.}}{3,300}$

does not take into account the efficiency of the pump and motor. Assuming the pump efficiency at 70 per cent, the resulting figure should be multiplied by $\frac{100}{70}$, and a further calculation is necessary for the motor efficiency. If the latter is reckoned at 50 per cent, the horse power required would be $\frac{\text{G.P.M.} \times \text{H.}}{3,300} \times \frac{100}{70} \times \frac{100}{50}$. A higher efficiency figure can be allowed for larger units than the smaller ones. Electric motors have a higher efficiency than internal combustion engines. The horse power required for internal combustion engines pumping against heads totalling 30-200 ft., with a flow of water varying from 5 to 100 gal. per minute, is shown in Table VI with an overall (pump and engine) efficiency of 30 per cent.

Assuming that the total head in the system (i.e., that used up in rise of ground surface, height of nozzles above ground level, friction in the pipes and pressure at the stand pipe) amounts to 100 ft., and the rate of flow is 35 gal. per minute, the horse power required would be $\frac{100 \times 35}{3,300} \times \frac{100}{30} = 3.5$ H.P., allowing for 30 per cent overall efficiency of the pump and motor.

Table VI indicates that a 3.6 H.P. motor is required. A 3 H.P. motor would probably do the work but a 3½ H.P. motor would provide a liberal margin of safety, as this table allows for an efficiency of only 30 per cent. For higher efficiencies, the figure in the table is multiplied by 30 and the resulting figure divided by the new efficiency figure. For instance, to calculate the power required for pumping 80 gal. per minute against a total head of 100 ft. with an efficiency of 50 per cent, the table indicates that 8.04 horsepower would be required at 30 per cent efficiency. By multiplying 8.04 by 30 and dividing by 50, this gives 4.82 as the horsepower required at 50 per cent efficiency.

The choice of a power unit must depend mainly on whether its work will be intermittent or constant and whether the average load will be exceeded at times, or not. For continuous running, a large margin of power is necessary if excessive wear and tear and over heating are to be avoided. If the load is intermittent, a smaller margin of reserve power will suffice and intermittent loading can be said to involve the unit in running under average load for not more than one hour, followed by a longer period under a reduced load. For work in which the unit is carrying a full load for several hours in succession, and irrigation pumping comes in this category, a much larger margin of reserve power is required. If the motor speed matches the pump speed a direct drive may be employed. If a belt drive is necessary, an allowance of about 7½ per cent should be made in the H.P. rating of the engine to allow for the frictional loss.

Chapter II. SPRAY IRRIGATION

The object of spray irrigation is to distribute the water uniformly and slowly in such a way that it resembles fine natural rain as nearly as possible. Two methods are commonly practised:

(1) In which the water is forced through orifices bored in metal pipes which run parallel with the ground surface. This is described immediately below.

(2) In which the water is radially distributed from "sprinklers" or rotary rainers (described on p. 25).

SPRAY-LINE SYSTEMS

The mechanism consists of a series of iron pipes, comprising large mains for carrying the water from its source, and lines of smaller pipes fitted with nozzles, to form the spray. This provides a more uniform distribution of water than the radial system. The mains may be fixed or portable and should be so arranged that as large an area as the pumping outfit will allow can be irrigated with a minimum of piping.

The Mains. In a stationary system, the pump and the mains are permanent and may be above or below ground, but with a portable system both pump and mains are transportable (Fig. 6). It is still a matter of some controversy whether permanent mains should be below or above ground level. To be able to cultivate the surface soil without any obstructions is a big asset, but even if the mains are below ground, standpipes will be necessary and these, when standing up singly, are liable to be broken off by tractors, etc. If the ground is only slightly undulating, and they are emptied by gravity, a portion of them may have to be buried extra deeply, which is a costly process. Also, underground mains are difficult to repair if a burst or leak occurs, and the damage has first of all to be located. Above-ground mains are cheaper to install and maintain, they are more easily flushed out and there is therefore less danger of frost damage. The stand-pipes and valves are less liable to damage by implements. Also they facilitate raising of the temperature of the water when the plant is in use. If underground mains are not sloped to enable them to be drained by gravity, they must be deep enough to escape frost injury, i.e., not less than about 2 ft., otherwise provision must be made for emptying them by compressed air. Permanent mains placed above ground should be supported about 12 in. above soil level on concrete blocks or "chairs" (Fig. 7).

The size of the mains depends on the rate of flow of the water and the distance it has to be pumped. For distances up to about 500 yards, a 3-in. main should be large enough for plants irrigating one to two acres at a time, but for an area up to four or five acres, a 4-in main carrying 12,000—15,000 gallons per hour would be necessary. All mains should be galvanized if possible, or rust will form inside which will ultimately clog the nozzles.

The mains are provided with stand-pipes and valves at points where the spray lines are connected. They will therefore be cut into lengths corresponding to the desired spacing of the spray lines, because the valves will have to be fitted at these distances. If it is desired to use spray lines simultaneously on either side of the main, then branch tees should be fitted,

each carrying two valves, which should run parallel with, and not at right angles to, the main. All valves should preferably be of the diaphragm type.

The Spray Lines. These are preferably of drawn steel, galvanized, and should run approximately at right angles to the mains, to which they are attached either by flexible hose or direct, with screw attachment. They are the smallest pipes in the system, the most usual internal diameter being 1 in. Their spacing depends on the size of nozzle used and the water pressure. A common spacing is in the region of 40 ft. but they may usefully be closer than this. If they are much further apart than this, difficulty in obtaining an equal distribution of water will be experienced in windy weather. They are erected at a height above soil level sufficient to clear the crops to be irrigated, 2 ft. generally being sufficient, and they rest loosely on movable supports placed at intervals equal to the length of each section. They can thus be rocked from side to side (oscillated) to distribute the water over an area about 20 ft. wide on either side of the line. To enable this oscillatory movement of the pipe to be made, a turning union must be fitted between the valve in the main and the end of the spray line and fitted either with a handle for hand turning or an oscillator worked by water pressure (Figs. 7 and 11).

The spray lines most commonly used in this country are in portable sections 16 ft. long, and their greatest length when made up seldom exceeds 300 ft. For longer lengths than this a larger diameter pipe may be necessary, and it may have to be "stepped," for the sake of economy. The sections of unstepped lines are joined by patent quick-couplings. Screw attachments are usually used for the sections of "stepped" lines.

Length of Spray Lines. An examination of Table VII indicates that the longer the spray line the greater is the variation in pressure and flow between the standpipe end and the distal end. This unevenness of watering cannot be corrected by increasing the pressure, and if lines exceeding 300 ft. must be used, it is necessary to have a greater diameter than 1 in. if excessively uneven watering is to be avoided. Thus the cost is correspondingly increased. The factors which determine the output of water from a given length of spray line are the rate of flow of water into the line and the size and spacing of the nozzles. The lower the pressure, the greater is the economy in energy, but the time of application is correspondingly increased; hence the labour costs are increased. In practice it is necessary to make a compromise between the two. Also there is a lower limit to the pressure, which is fixed by the fact that the throw must be sufficient to cover the area to be irrigated. Where only one size of pipe is used in the spray line, complete interchanging of the sections is possible, an important factor.

Friction in Pipes. The friction set up by the water travelling through pipes is easily translated into feet of head, and the pressures required to overcome friction in each 100 ft. of galvanized wrought-iron pipe for different rates of flow are set out in Table IV. These figures refer to pipes without nozzles.

The slope of the land either lessens or intensifies the pressure variation in the mains and spray lines. Thus, if the source of supply is at the highest point of the farm, the slope of the land will probably compensate for the loss of head due to friction.

In determining the quantity and sizes of piping required, the first essential is to know the capacity of the water supply. When the available quantity of water and the capacity of a given length of sprayline at a given pressure are known then the necessary quantity of piping for linking the water source to the spray lines can be calculated. Friction in the pipes means wasted energy, since additional power is required to overcome it. This can be reduced by installing pipes of sufficiently large size to reduce the friction to reasonable limits.

Nozzles. In practice it is best to use brass nozzles which are screwed into holes bored in the spray lines. They can be removed for cleaning and have a long life. Their spacing on the line varies considerably, depending on the pressure available, but the most usual spacing is 2 ft.

Erection of the Spray Lines. In erecting the spray lines, the separate sections and their supports are first laid on the ground in their approximate positions. The section nearest to the valve on the main is the first to be placed in position on its support, and the second section is then coupled to it, one support being allowed to each section. Further sections are added until the line is completed. The section nearest the main is then coupled to the valve by a length of flexible hose, the internal diameter of which should not be less than that of the spray line.

Management of the Plant. No hard and fast rules are applicable to the use of an irrigation plant. The choice of the time at which the plant is used depends almost entirely on the condition of the crops, but the weather and the labour available for erecting the lines must also be considered. If the soil is heavy, the water must be applied sufficiently slowly to prevent puddling, and frequent turning of the lines will be necessary. When sufficient water has been applied, the flow is stopped and the spray lines are uncoupled, each section being transported to the next series of supports where they are re-assembled and the water again turned on. If, however, a second series of spray lines is available for erection while the others are in use, the pumping machinery can be kept running while the first series is being moved, and loss of spraying time will be avoided.

Filtering of the water is best done at the source but if this is not adequate a cone-shaped filter can be placed in the pipe at the commencement of the spray line, either separately or combined with the turning union. Some makers provide a flushing valve at the end of each spray line so that any dirt accumulating in the pipe can be washed out periodically. If a flushing valve is not used, the end cap should be removed, and the line flushed out before starting the watering.

The Oscillator. This is a hydraulically driven device for turning the spray lines whilst they are in use (Fig. 11). The shorter the length of line, the easier the oscillator works and the less head of water is needed to drive it. One oscillator is necessary for each line. Oscillators are particularly advantageous where heavy land is irrigated as the continuous movement of the line prevents puddling of the soil, a trouble likely to occur where the lines are turned by hand only. Oscillators can be obtained which move through an angle of 110 degrees from horizontal to vertical and vice versa on either side of the spray line, or through 55 degrees on either side of a line drawn vertically from the spray-line. Slow-moving oscillators are preferable to those which

move fast, as they are less liable to break down; they absorb a smaller head of water and the time-lag at the end of the throw does not lead to such an uneven distribution of water as accompanies faster moving models. An oscillator is now made which combines the turning of the spray line with the working of a nutrient solution pump, but a high water pressure is necessary for the satisfactory working of this on long lines.

Winter Storing. Before the winter sets in, the pipe system must be drained and all portable parts should be cleaned and carefully stored in a dry place. Any parts liable to rust should be greased, and the pump and engine, if necessary, overhauled. In the spring, the whole pipe system should be thoroughly flushed before use.

Typical Plant A

(A SYSTEM SUITABLE FOR THE SPRAY IRRIGATION OF AN AREA OF ABOUT 80 ACRES)

Before this plant was installed, all hedges and trees were cleared and ditches filled in. A series of concrete roadways runs through the irrigated area, and the pumping plant is situated in the centre (see Diagram 4 and Figs. 3, 5, 7, 8 and 9). The permanent mains below ground and the sub-mains above ground are laid at right angles to the central roadway in straight lines so that the land is divided into rectangular blocks each of about 10 acres. The water is supplied from two boreholes, 196 ft. and 224 ft. in depth, and about 50 yds. apart. It is raised on the air-lift principle, a separate direct-drive, air-cooled compressor being used for each well. Each compressor is arranged in such a way that it can operate either well singly or in conjunction. The water flows into a tank holding 69,000 gal., built on brick supports so that its base is about 3 ft. above soil level. A steel partition divides it into a main tank and an 8-ft. wide settling tank. The water flows over the side into one end of the settling tank, then through its whole length (about 40 ft.), and finally over a "V" notch situated on the top of the partition at the far end. The partition is 6 ft. high. Thus any sediment brought up in the water has a good chance of settling before the water begins to enter the main tank. When the main tank is full, float switches automatically switch off the air-lift pumps. Similarly, when the tank is being emptied and the water reaches a low level, another float switch automatically switches off the motor operating the booster pump.

Situated between the pump house and the outlet to the main is a "hydrostat chemical injection unit," whereby nutrient solutions can be added to the irrigation water as it passes into the main. The water can be heated by 4-in. hot-water pipes which circulate through the settling tank and connect to a boiler outside.

The main starts at 5-in. internal diameter, then reduces to 4 in. and finally to 3 in. Sluice valves are fitted to the underground mains so that each half of the plant can be isolated from the other, if necessary. The 4-in. underground main (A) runs at right angles to the road for a distance of 350 ft. on either side. Each end then connects with two 4-in. underground mains (B), which run parallel to the road through nearly the whole length of the area.

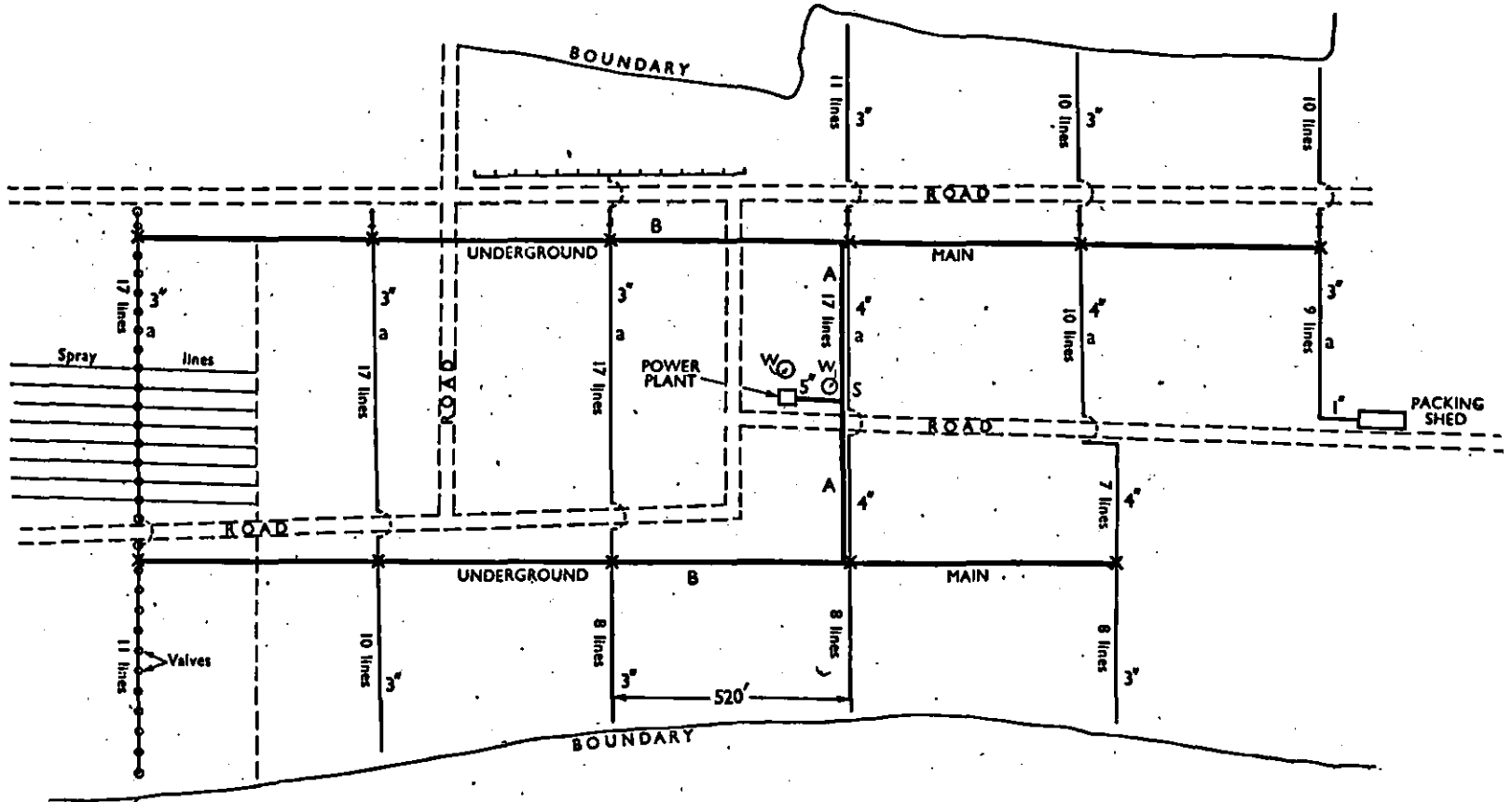


DIAGRAM 4. Typical spray system for a vegetable farm.

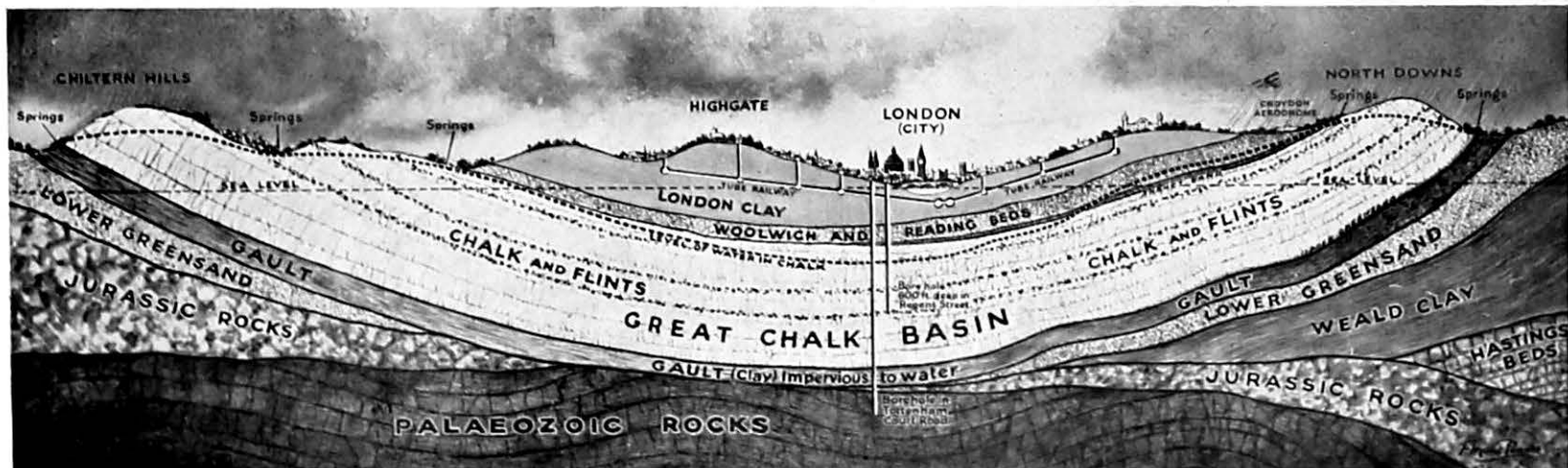


FIG. 1. The Great Chalk Basin, source of London's underground water supply.

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[Courtesy LeGrand, Sudcliffe & Gell, Ltd.]

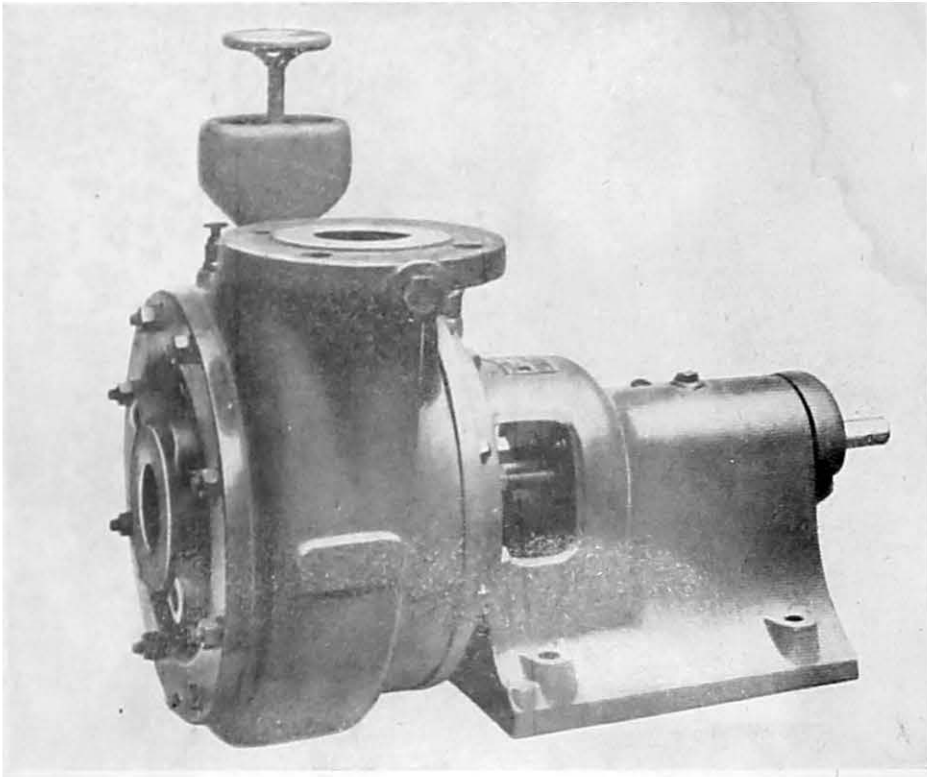


FIG. 2. Direct coupled pumping set. Electric motor and centrifugal pump.
[Courtesy Sigmund Pumps Ltd.]

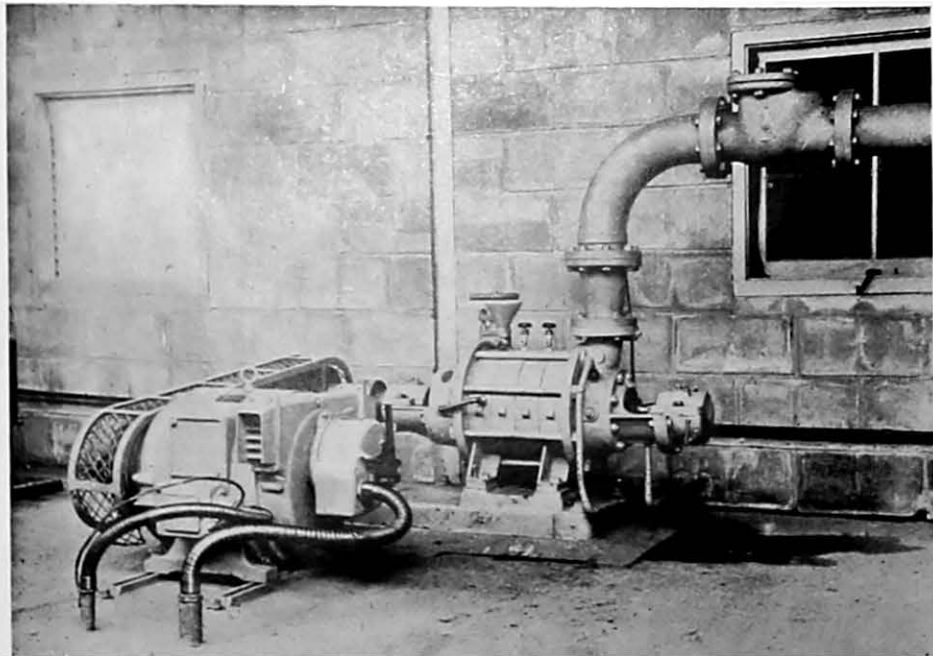


FIG. 3. A belt-driven pumping unit.
[R. A. Malby & Co.]

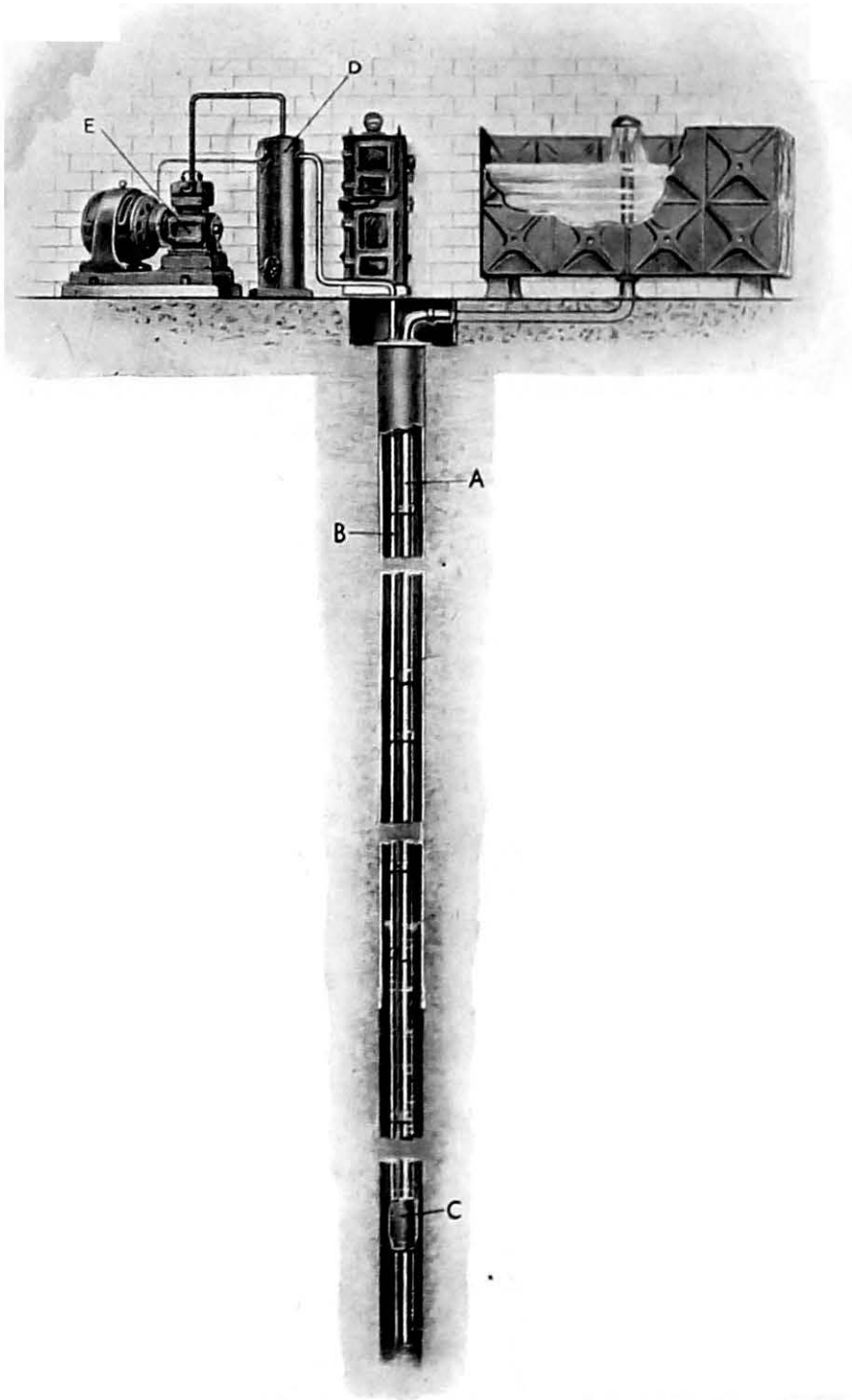


FIG. 4. Air lift pump, in section.

[Courtesy LeGrand, Sutcliffe & Gell, Ltd.]

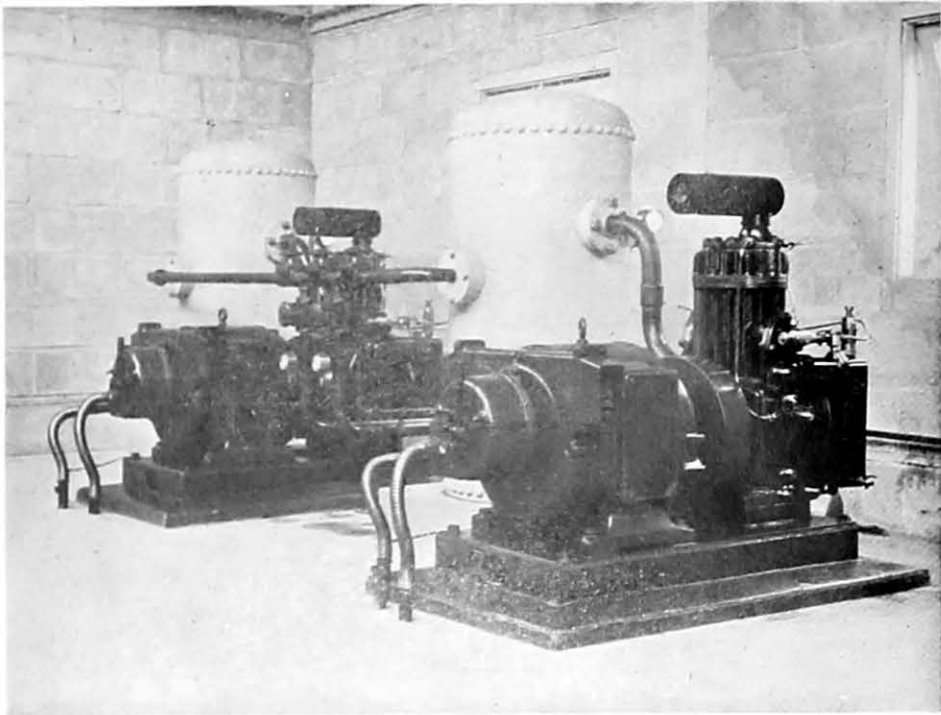


FIG. 5. Air lift pumps, showing power units, air compressors and receivers.
[R. A. Malby & Co.]

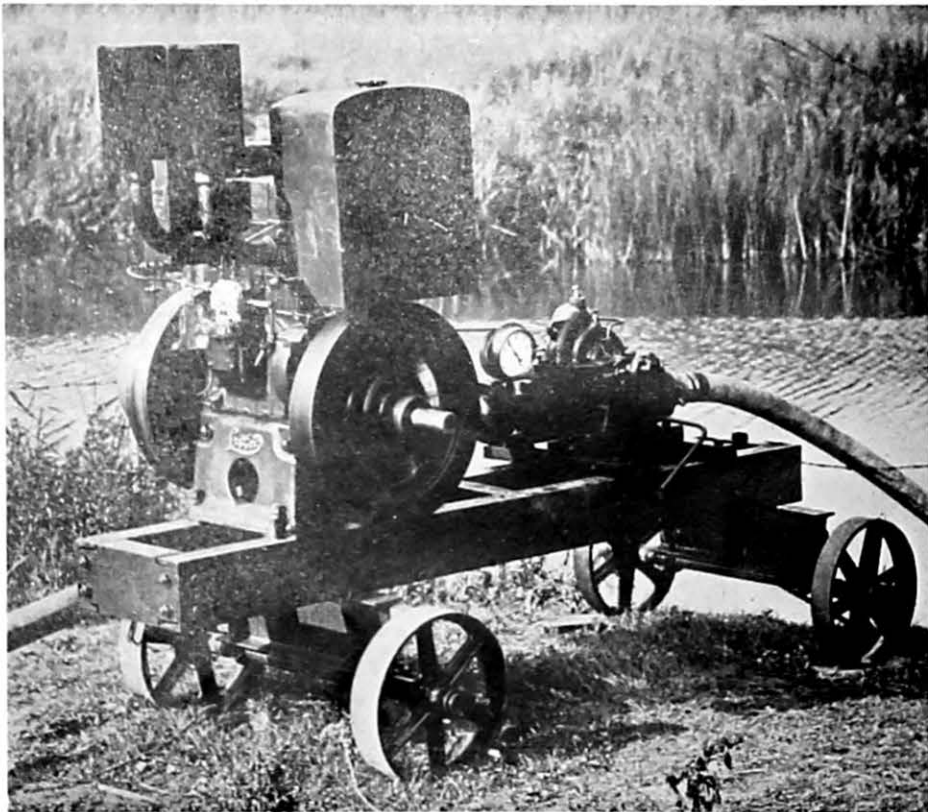
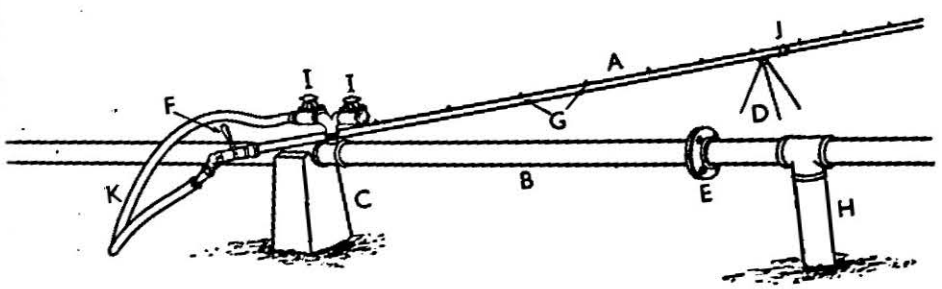


FIG. 6. A portable centrifugal pump and power unit.
[Evesham Journal.]



FIG. 7. Irrigation main with connexions.

R. A. Malby & Co.



Key to above illustration.

- | | | | |
|---|-----------------------------|----------------------|-------------------------------------|
| A. Spray line. | B. Main. | C. Support for main. | D. Support for line. |
| E. Joint to facilitate dismantling, if necessary. | F. Handle for turning line. | G. Nozzle. | H. Connexion with underground main. |
| I. Double valve. | J. Coupling. | K. Flexible hose. | |

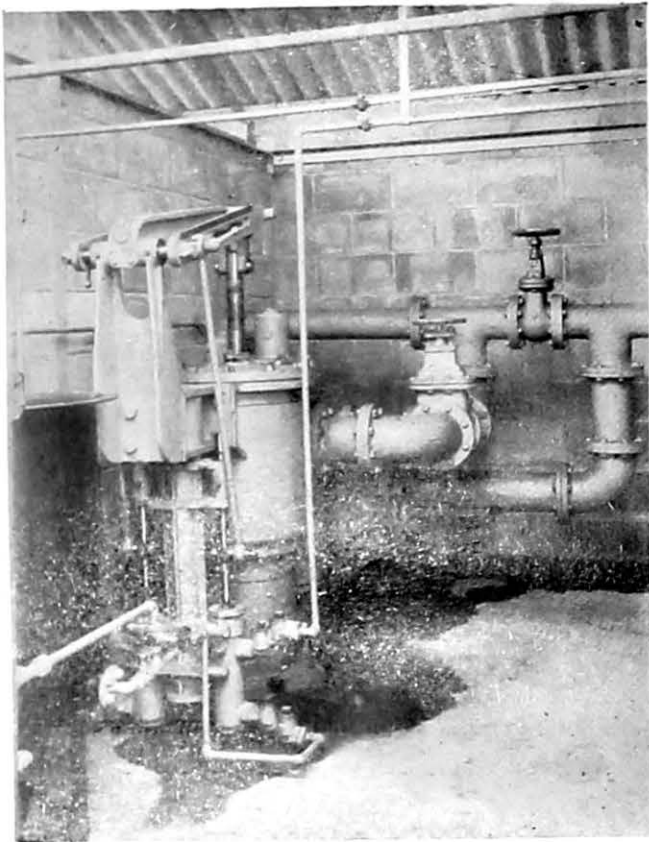


FIG. 8. Hydrostat chemical injection unit.

[R. A. Malby & Co.]



FIG. 9. General view of irrigation power plant, with storage tank.

[R. A. Malby & Co.]



FIG. 10. Portable spray line on permanent supports.

[Copyright E. Skillman.]

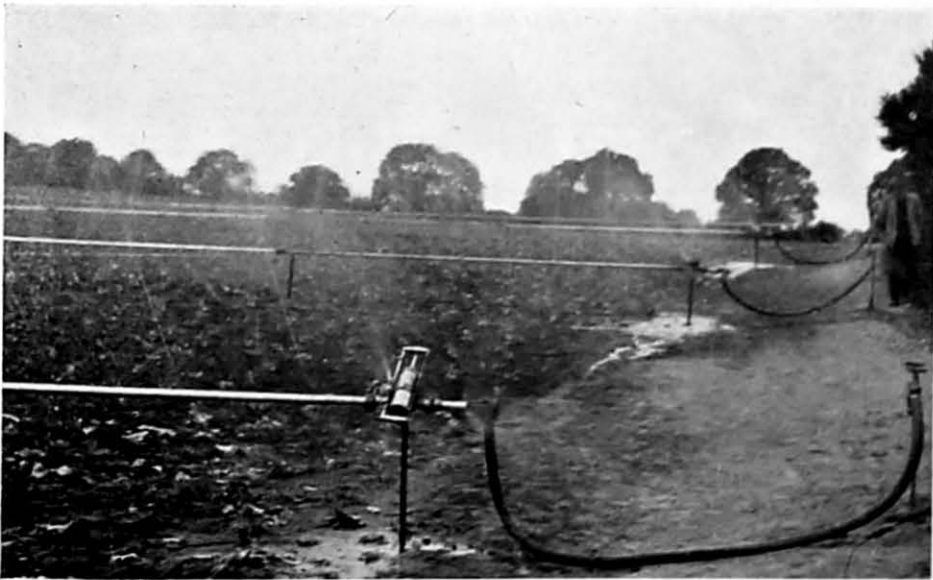


FIG. 11. Spray line with oscillator.

[Courtesy C. P. Kinnell & Co., Ltd.]

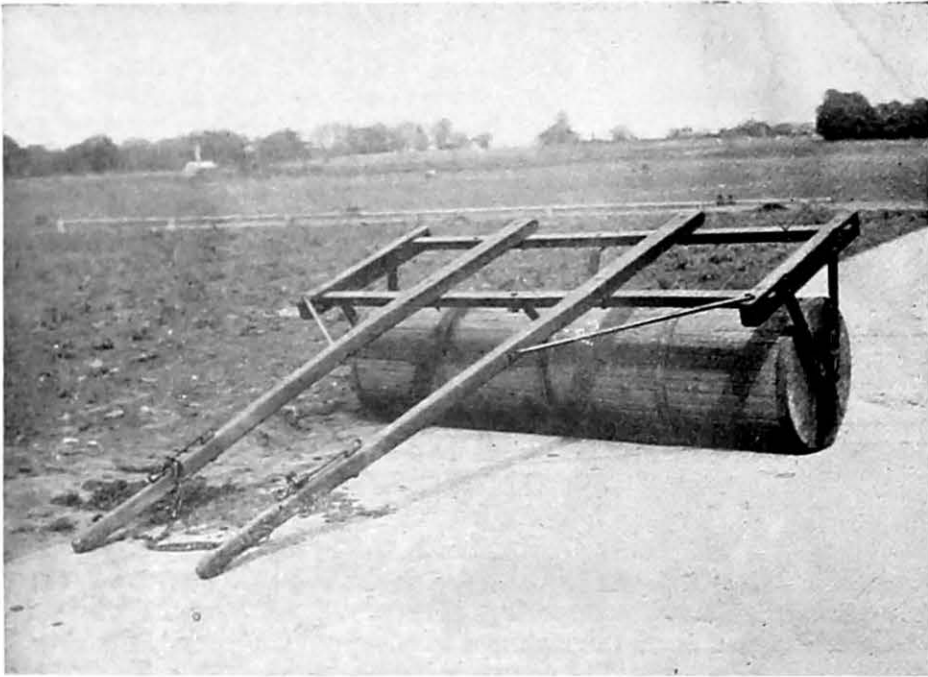


FIG. 12. Wooden roll.

[R. A. Malby & Co.



FIG. 13. Irrigation of soil in glasshouses.

[Courtesy G. P. Kinnell & Co., Ltd.

The above-ground sub-mains (a) are mostly 3 in. in diameter and run at intervals of 520 ft. and at right angles to the main road, under which they are carried throughout the length of the farm. Each above-ground sub-main is connected to the underground mains at two points (marked on the diagram by an "x") by 4-in. "risers", so that the whole forms a complete circuit. Thus when the battery of spray lines is being used in certain positions, the water is supplied to it from both ends, and in this way a more even distribution is obtained than if it all entered at one end, i.e., if the sub-mains were fed by a single central main, instead of the two mains.

The 16 portable spray lines can either be used in a single block, covering about 4 acres, or groups of them can be used on different parts of the system, provided the total area if irrigated at once does not exceed approximately 4 acres. Another 16 lines are available for erection whilst the first 16 are in use. The sub-mains carry 1½-in. branch tees at intervals of 40 ft., each tee carrying two 1¼-in. valves, to which the spray lines are attached by armoured hose. The lines are 1-in. internal diameter, and in sections of 16 ft. The normal working length is 260 ft., and the double valves enable them to be used on either side of the sub-mains. The nozzles are 2 ft. apart, the pressure at the furthest valve being not less than 70 lb. per sq. in. when the plant is working at full capacity. The nozzles have a low coefficient of discharge so that, with the high pressure, a very fine spray is produced, an inch of water being applied in approximately 8 hours.

Typical Plant B

(A MEDIUM-SIZED PLANT BASED ON THE SYSTEM OF PORTABLE SPRAY LINES WITH PERMANENT SUPPORTS.)

This plant was erected in 1927, and is based on the Skinner (U.S.A.) system. It differs fundamentally from the methods previously mentioned in that there is only one nozzle line working at a time, and that a long one instead of a number of short lines. The supports for this are permanent and about 4½ ft. in height, the spray line, however, being portable (Diagram 5).

The water supply is from the main under a pressure of about 40 lb. per sq. in., and the road carrying this supply runs past the field which is irrigated. From it the grower has installed a 3-in. main into the field and stand pipes (3 in.) with valve are placed every 51 ft. and rise to a height of 4½ ft. above soil level (Fig. 10). Opposite each stand pipe is the row of permanent supports made of galvanized pipe (1 in.), embedded in small concrete blocks. The supports are spaced at 18 ft. in the row and each carries an easily detachable patent roller bearing in which the spray line rests. There are eight rows of supports sufficient for irrigating approximately 6 acres.

Spray Lines. The spray line is nearly 600 ft. long. The line is "stepped" into five sizes of pipe, viz., 185 ft. of 2 in., 120 ft. of 1½ in., 112 ft. of 1¼ in., 100 ft. of 1 in. and 75 ft. of ¾ in. in order to economize in the cost of the line. The nozzles are placed at 3-ft. intervals (the holes to take them were made by a hand-operated drilling machine).

When the crop has received sufficient water, the valve at the end of the spray line is closed and each section is unscrewed with a spanner and carried to the next row of supports, where they are again reassembled and the water turned on. The one line when working will spray about three quarters of an acre.

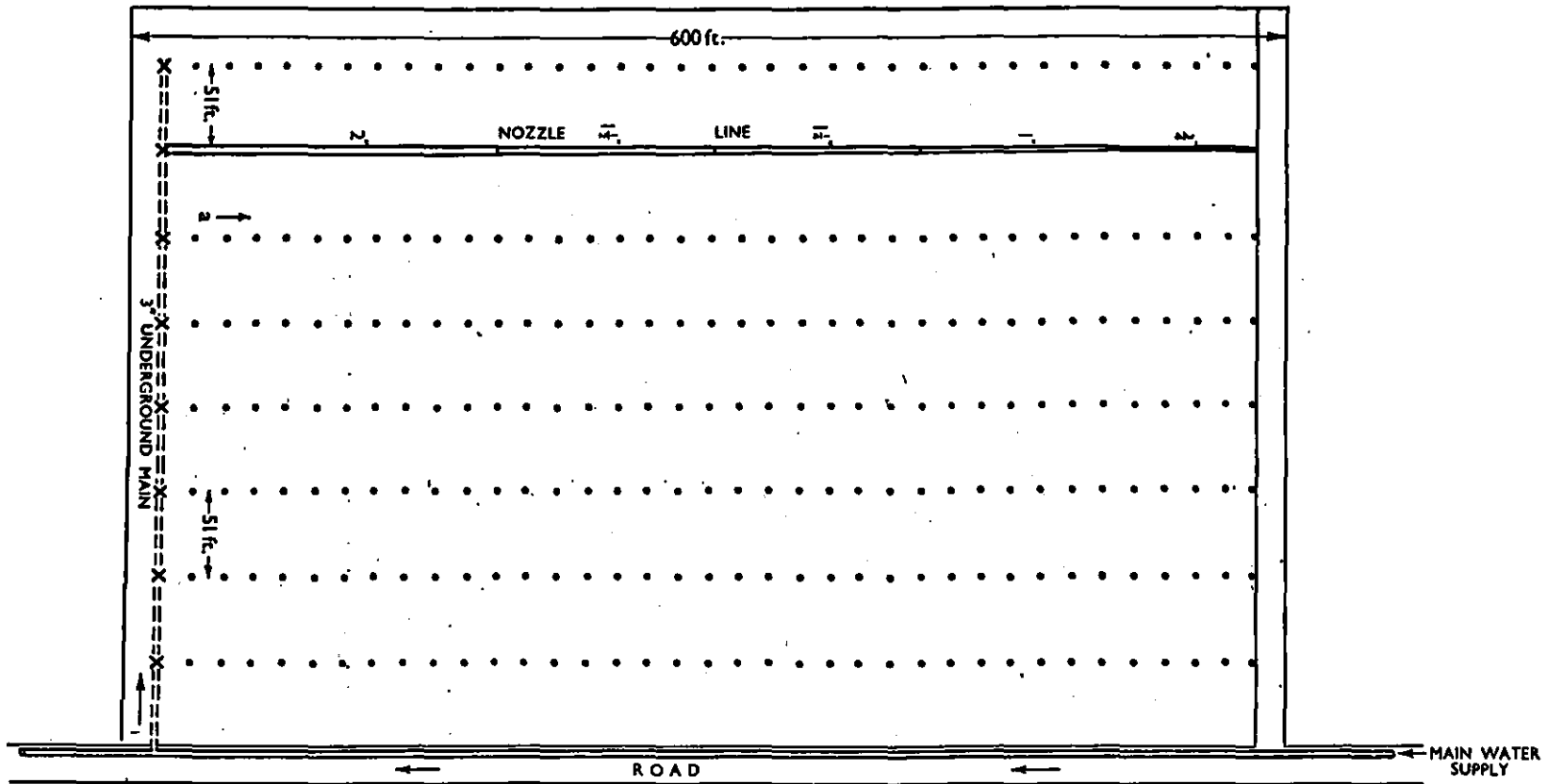


DIAGRAM 5. Medium-sized plant with portable lines on permanent supports.

The union for turning the spray line is attached to the 2-in. section at the standpipe and very little pressure is required to turn the whole length of pipe and thus enable spraying to take place in any desired direction. In three stages the line can be turned to cover the 25½-ft. strip of land on either side of the supports.

Using one spray line, 1 in. of water can be applied in about seven hours. If there is sufficient water it is possible to use two long pipe-lines at one time but with a 3-in. main this involves running the water at its full capacity. To use more than two long spray lines without the help of a booster pump, it would be necessary to install a larger pipe than the 3-in. main.

The cost of installation including two spray lines amounted (pre-war) to about £40 per acre (for 6 acres) including connexions to the main, which were the most costly part.

CIRCULAR SPRAY SYSTEMS

There are various forms of rotating sprinklers designed for private gardens, bowling greens and farm crops. The apparatus consists of one or more nozzles, generally on a rotating pipe, the power for rotating the pipes being provided by the water pressure. Some of these sprayers have a fixed nozzle attached by a turning union 3 to 6 ft. above ground level to an upright pipe which is supported by a stand, the whole being portable for moving to different positions on the land to be irrigated. The larger circular sprayers or rainers cover a circle of 100 to 350 ft. or more in diameter, and are usually run from centrifugal pumps powered by Diesel engines.

In some models, the rotation of the apparatus and the breaking up of the main jet of water are performed by an auxiliary jet. In others, these functions are performed by a flywheel which is fixed close to the main jet. The force of the jet turns the flywheel which in turn operates the mechanism for rotating the whole apparatus. Connexions to the main may be made by flexible hose, the length of which depends on the spacing of the mains or sub-mains.

Owing to the fact that the areas irrigated by these sprayers are theoretically in the form of circles there must be some unevenness in the watering because if the circles only touch, some of the land receives no water and if they overlap, so that all the land is watered, a proportion receives twice as much water as the rest. In practice, however, the area covered is not always a perfect circle owing to the effect of the wind which, if high, will cause considerable unevenness in the distribution of the water. The larger units are capable of applying up to ½ in. of water per hour over more than two acres. The length of the jet exceeds 175 ft. and under such conditions some unevenness and coarseness in the watering may occur unless full pressure is maintained. So that while the large sprayers may be suitable for firmly established forage crops, or certain perennial plants, they would not be suitable for watering small plants, especially those with a shallow root system, because at certain parts of the circle covered, such plants tend to become washed out of the soil. In the U.S.A., circular sprinklers, supported 4 to 6 ft. above ground level, are used largely for the irrigation of fruit plantations. In this country, circular sprayers have given good results with various established vegetable crops, and also with sugar beet, mangolds, potatoes, fodder crops and grassland.

Chapter III. SOILS AND CROPS

SUITABLE SOILS AND THEIR PREPARATION

Soils that respond best to irrigation are the light sandy loams and brick earths on gravelly subsoils. Infertile soils do not yield a sufficient crop to justify the cost of irrigation and the best results are obtained from soils rich in humus and overlying a subsoil that provides good drainage. Thus the physical condition of the soil is one of the chief factors which have to be studied when irrigation is used. This condition can be upset very easily by the addition of water during periods of drought, and it is of little use to water a sandy soil or brick earth which contains little or no organic matter. The manure cart and the irrigation system should be worked in close conjunction. Heavy clay soils are seldom suitable and tend to puddle even with the spray irrigation. That their rate of absorption of water is low, is indicated by the fact that the average clay soil will take 16 hours to absorb 1 in. of rain. Certain plant foods are more easily leached out of the soil than others, and on very light soils it is essential to maintain a high content of organic matter so that these plant foods can be retained against leaching.

Loss of Soil Water. It is necessary to differentiate between irrigation for assisting a growing crop and irrigation for improving the working conditions of dry soil. With the former, the best results are obtained by the slow application of water in the form of a spray or mist, whereas in the latter case water can be applied more rapidly. The equivalent of an inch of rain makes the soil more workable for seed sowing, etc., and provides a small reserve of moisture which, if supplemented by a limited fall of rain, may be sufficient to carry a crop to maturity, e.g., lettuce. In summer, however, losses by evaporation are substantial and after a summer rain, no amount of cultivation will prevent a loss of about $\frac{1}{4}$ in. of water from light soils to about $\frac{1}{2}$ in. of water from medium soils. After this, evaporation will be slower, provided the soil is not disturbed too deeply. If the soil surface is wet, it loses water rapidly, but as the surface dries so the rate of loss decreases. After a rain in summer, $\frac{1}{4}$ to $\frac{1}{2}$ in. of water can be lost in three days by evaporation, with a further loss of about $\frac{1}{2}$ in. in about two weeks. A further $\frac{1}{2}$ in. can be lost in three months, bringing the total loss by evaporation to about $1\frac{1}{2}$ in. This applies to unplanted soil. An inch of water on sandy soil which is really dry will moisten it to a depth of about 9 in. but there is no evidence that surface cultivation will prevent the evaporation of this water, except in so far as it restricts weed growth. Heavy soils when really dry, require about 2 in. of water to moisten them to a depth of 9 in.

Loss of Soil Water

Table II* shows the estimated mean monthly transpiration of water from an area cropped with grass which always received an adequate supply of water. The Rothamsted figures are based on mean data for 1931-40, the Lympne figures on mean data for 1940-44 and for Shoeburyness, on mean data for 1940-43.

Use of the Table. Assume that there is a continuous crop cover which it is desired to keep growing at the maximum rate so far as water supply is concerned. Using the Lympne figures, and assuming the monthly rainfall

* Table II, and other tables, will be found at the end of the bulletin.

is 2.5 in. in all months, then up to and including April, rainfall exceeds transpiration and the excess will drain away. During May, a deficit of 0.8 in. (i.e., 3.3 - 2.5) will be built up. i.e., if the soil is to be brought up to field capacity at the end of May, 0.8 in. of irrigation water must be applied. Supposing that irrigation water is not applied, during June the deficit will increase by 1.5 in. (4.0 - 2.5), and during July by a further 1.2 in., i.e., at the end of July the deficit would total 3.5 in. This is probably the upper limit for full growth of grass and will be beyond the safe limit for shallower-rooting crops but within the limit for the deeper rooting ones. For grass, therefore, with a monthly rainfall of 2.5 in., irrigation must be applied or the crops will suffer during August. It should not be necessary to bring the moisture content of the soil right back to field capacity; if 1.5 in. of irrigation water are applied, this would reduce the deficit to 2 in. and during August this would increase to 2.7 in. The deficit would be made up during September and October, and drainage would be resumed in November.

The deficit can be easily worked out for other rainfall distribution but two generalizations must be borne in mind. For grass, the deficit should not be allowed to exceed $3\frac{1}{2}$ in., and for shallow-rooted market-garden crops the safe limit may well be between $1\frac{1}{2}$ to 2 in. Secondly, if abnormally heavy rainfall occurs, exceeding in amount the estimated deficit, the excess will be lost as drainage and the balance cannot be carried forward. If the average May-August rainfall figures for Lympne are used, then in the case of grass, a deficit of 6 in. would be built up by the end of August, i.e., the safety limit would be exceeded by $2\frac{1}{2}$ in.

The Use of Soil Moisture Meters. The appearance of the soil surface only gives a rough guide to the soil moisture conditions. The soil may be wet and muddy on top and quite dry below, or dry and crusted on top and well supplied with moisture beneath, under different weather conditions. Growers have therefore long wanted a more precise guide to soil moisture conditions. One method of attaining this is to make a boring with an auger, and rub the soil between the fingers. Tests have been made with an instrument designed to measure accurately the tension of the moisture film surrounding the soil particles, which is nil in saturated soil and rises as the soil dries (31). The wilting point of plants is equivalent to a moisture tension of many atmospheres, but experiments have shown that when the soil moisture tension in the main root area has reached about 45 cm. of mercury as shown by the tensiometer, an application of water will be likely to improve the growth of plant or fruit (32). It has not yet been found possible to produce commercially a tensiometer suitable for putting on the market.

Crops Suitable for Irrigation

Whether it is worth while for a crop to be irrigated depends on whether its value after irrigation allows for a margin of profit after the cost of irrigation has been deducted. For this reason, only the higher priced crops such as vegetables and flowers, which are very adversely affected by comparatively short periods of dry weather and the prices of which fluctuate widely in inverse ratio to the supply and quality, repay the cost of irrigation. Plants that are shallow rooting suffer more during periods of drought and improve more quickly when irrigation water is applied than deep rooting plants.

Cauliflowers, celery, chrysanthemums, mint, narcissi, early potatoes, radish, rhubarb, onions, spinach, sprouts, turnips and young plants of broccoli, cabbage and lettuce respond favourably to irrigation and give improved crops. Any plants in the young stage can be watered by the overhead irrigation method with safety, but older plants that have commenced to mature are more difficult and may be damaged. Hearting lettuce may be scorched if the watering is done during very bright sunlight and cauliflowers showing curd may be discoloured and damaged. It is not advisable to water seakale, a crop which is capable of withstanding severe drought.

Where an irrigation plant has been established it is important to arrange the cropping of the land to make full use of the plant; constant and continuous cropping must be the aim. When ready, crops must be lifted and marketed and the land cleared and replanted to another crop.

Irrigation and Soil Treatment for Vegetable Crops

It is only too evident that where irrigation is practised the programme of soil cultivation must be adjusted to suit the needs of irrigation. When the soil is thoroughly moistened by natural rain, this generally occurs during dull periods when there is a reasonable chance of the soil remaining moist for some time and its cultivation and cropping can be planned accordingly. Under artificial irrigation, however, the soil receives water during hot, dry periods and its cultivation and cropping has to be considerably speeded up so as to take advantage of the water before it is lost by evaporation.

When dry soil which requires deep cultivation first is to be seeded or planted there is some difference of opinion as to whether the soil should be watered before or after ploughing. As a general rule it can be assumed that light, open soil may be watered after ploughing and harrowing, but heavy soils (e.g., alluvial silts) may be watered prior to this cultivation. There are certain light soils, however, which tend to "cap" after watering and these should be irrigated before ploughing.

Where watering is done before cultivation, the farmyard manure is spread over the surface before the watering. The nozzle lines are then erected and approximately 1 in. of water is applied if the soil is very dry. Ploughing and harrowing must follow as soon as the soil texture permits, and the seeds or plants are then put in. It is important not to irrigate more land than can be dealt with quickly, because in hot weather the water will evaporate very rapidly and the value of the watering may be lost. If farmyard manure is not used at this stage it is advisable to apply some other organic manure, a useful dressing being a mixture of 6 to 7 cwt. ground hoof, 4 cwt. bone meal, 2 to 4 cwt. sulphate of potash per acre; the lighter the land, the higher the proportion of potash that should be used. This mixture may be applied and worked into the soil after the first watering. Lettuce respond best to coarsely ground hoof, but for cauliflowers it is best applied in finely ground form. Provided the soil temperature is sufficiently high, all crops grow so quickly after irrigation that for the rate of growth to continue, an adequate food supply must be available.

The climatic conditions which follow immediately after the land has been irrigated fix the moment at which ploughing may recommence. The water should have soaked in so that the land is in a friable condition. If cultivations are started too early the soil may be worked into a sodden condition and

dry out very quickly in hot weather, becoming almost like a brick. On the other hand, it is just as detrimental to leave the land too long as it is to plough it prematurely, since in this case the water quickly evaporates, a hard cap may form and further waterings are necessary. As a rule, land should be ready for cultivation the day following watering. The ploughing should be carried out to a depth of about 9 in., and the sodden farmyard manure is drawn into the furrow during the ploughing. After ploughing, the land, if very light, is rolled with a light wooden roller (Fig. 12) and this should be followed by a seed harrow. After the last harrowing, the land should be ready for planting or seed sowing.

After the seed has been sown it is seldom advisable to roll the land unless the weather continues hot and dry, when a very light pressure with a wooden roller may be given. Excessive heating of the soil can be avoided by spreading hydrated lime on the surface at the rate of 10 cwt. per acre.

On soils where cultivation is done before watering, the manures are ploughed-in in the usual way and after one harrowing the soil is thoroughly watered. When the surface is sufficiently dry to enable light cultivation, e.g., in about 24 hours, the soil receives a further harrowing and the seed is sown. Whether irrigation is carried out before or after ploughing, after the seed is sown or a crop planted, the surface soil should receive a light cultivation, either with horse hoes or a light scuffle.

Application of Water to a Growing Crop. No hard and fast rules can be laid down as to the ideal time to apply water to the crops, and the grower must be guided by careful observation and experience. The appearance of the plants and the condition of the surface soil and subsoil will indicate whether the crop is in need of water or not. Great care must be exercised in deciding on the time and quantity to apply, since it is easy to damage a crop by irrigation. For instance, it is unsafe to water lettuce (in which the hearts are formed) by overhead irrigation, particularly in hot weather, as scorching is likely to result. The danger of scorch will be obviated if irrigation is carried out at night time or during the early morning or the evening. With shallow rooting crops, it must also be borne in mind that if, in a prolonged period of dry weather, irrigation has been started, it must be continued according to the needs of the crop until either the crop matures or the weather changes. Otherwise the crop is likely to suffer in consequence.

The usual quantity of water given at one application to a growing crop amounts to 11,000 gal. per acre or the equivalent of about $\frac{1}{2}$ in. of rain.

A crop which grows rapidly, e.g., cauliflowers, will require water every 10 to 14 days under drought conditions; if water is necessary for cauliflowers after the curd has formed, it should only be applied in the evening or early morning. If water is applied to a curd which is warm after or during sunshine, rotting is sure to follow, often after cutting and marketing of the crop.

With quick maturing crops such as lettuce it is not uncommon for irrigated soil to dry out before the crop is ready for cutting, in which case an application of finely atomized water may be made in the evening or early morning of a hot day, or at any time on a dull day. A heavy watering is seldom necessary, about $\frac{1}{4}$ in. usually being sufficient.

Under very hot and dry conditions, a rapidly growing irrigated crop, in full leaf, such as self-blanching celery or cauliflower, will often require substantially more than 1 in. of water for the soil to be moistened to a depth of 9 in. or more. The main reason for this is that a quantity of the water is held in the hollows of the leaves and stems, and the surface area of the plants has first to be saturated before any quantity of water finds its way into the soil.

Rhubarb responds very readily to watering specially in its first year. A dressing of 2 cwt. sulphate of ammonia per acre applied to this crop before watering, benefits the crop. If the land in which rhubarb is planted is very dry, the roots are inclined to become hollow in the first year and such roots seem to be more susceptible to Crown Rot. This nitrogenous dressing, coupled with the moisture, appears to fill out the root tissues and prevents the crown from becoming hollow. Overhead irrigation is said to encourage canker in parsnips, but as they are deep rooted, they should seldom require irrigation in this country. Potatoes readily respond to spray irrigation and on light soils the increased crop should be sufficient to justify the extra expense in dry seasons. The treatment is mainly confined to the early crop.

It has been found that the various crops when irrigated respond very differently to a standard system of manuring, and much work requires to be done to ascertain the ideal systems of manuring for the different crops when they are to be irrigated. For instance, with cauliflowers if phosphate is applied, the application must be so timed that it only becomes available after the curd has formed. If it becomes available before the curd has formed there is considerable danger of buttoning. Conversely, for lettuce to give the best results, phosphates must be available before hearting commences.

Different characteristics of different crops must be kept constantly in mind, such as rooting habits and responsiveness to water; the best method of applying water to each type of soil must also be considered. Where the water supply is limited the roots must be deep and not held near the surface by early light irrigation. Deep-seated moisture within certain limits stimulates greater root development and this results in a greatly increased absorbent surface. Notwithstanding this greater absorbent surface, if the water supply is restricted, the portion of the plant above ground is often incapable of much development. Conversely it is usual to secure extensive above-ground development from a limited root system in moist fertile soil (52). Unless the moisture supply is constant, such a condition is dangerous in crop production since even moderate drought at a critical period may enormously lower the yield.

As in all farming, no hard and fast rule can be laid down for irrigation or cultivation as different soils demand different methods. In common with the other branches of horticulture the use of irrigation largely develops into the application of common sense combined with a keen power of observation, although it may be said that the principal mistake with the use of an irrigation plant is to give the crops too much water with too frequent application. It may even be said that at a certain stage in growth the plant may benefit by having an opportunity of acclimatizing itself to dry conditions. If this is done the application of water as a finishing touch will produce remarkable results. During hot weather great benefit can be obtained from applying the water in the form of a mist over the crops at night; they will then

absorb sufficient water to carry them on through the following day. Care should be taken that this work is only done during the evening, night or early morning hours which are the times when the plant is so treated by nature.

Irrigation of Fruit Crops

Irrigation of fruit has not been widely practised in England, but preliminary experiments at East Malling Research Station have given very encouraging results. Even in a wet year, watering James Grieve apples by the furrow method increased fruit size by 11 per cent. The amount of water used was 5 in. in June and 3½ in. in July. This proved to be excessive and wasteful, but it was concluded that irrigation suitably applied would be justified for apples in dry seasons in certain areas of the country (34).

Since fruit plants, especially the tree fruits, have deeper root systems than most vegetables, heavier applications of water are justified than are commonly given to vegetable crops. On good deep loams it should be quite feasible to apply 3 in. of water at one application for fruit trees, with consequent saving in frequency of irrigation and of evaporation losses. On shallower soils, 2 in. should be sufficient, but more frequent applications might be necessary. With strawberries, to allow for surface evaporation, applications of 1 to 2 in. at a time are probably sufficient for practical purposes.

The furrow method of application is quite practicable under fruit trees, and it is the commonest method in many parts of the world. It is more wasteful of water than the spray method, however, and is most economic where supplies of water are available at low pressure and low cost, as from a stream. The spray method distributes the water more evenly and has proved excellent for small fruits such as strawberries. It is also possible to use it for raspberries if the pipes are supported on stands at a height greater than the raspberry canes. It is difficult to use the oscillating spray-line method under bush fruit trees, but not so difficult under half-standard or standard trees, and in Australia and America it is used on a large scale on top fruits.

Chapter IV. OTHER FORMS OF IRRIGATION

SURFACE IRRIGATION

This form of irrigation is practised on row and silage crops and fruit plantations in this country on a small scale.

Surface irrigation from rivers and wells is extensively employed in arid regions in all parts of the world. In India, a considerable area is irrigated by canals supplied from rivers and dams. Large tracts of land are irrigated by river water in Australia. Extensive areas are irrigated by surface methods in Canada and the U.S.A., in the Anglo-Egyptian Sudan, upwards of 1,000 square miles are irrigated by similar methods. In Ceylon, nearly 600 square miles are irrigated for rice growing, and for this crop, smaller but considerable areas are irrigated in Malaya, British Honduras and British Guiana. In South Africa, surface irrigation is used for citrus and other fruits, and also for lucerne. In Mauritius it is used mainly for sugar cane. In the Sudan, cotton is the principal crop grown under irrigation, and in Palestine, Iraq and India, cotton and cereal crops are irrigated.

The two most common systems of surface irrigation are the furrow and the flooding methods, the sources of water being similar to those indicated for spray irrigation. The quantity of water used is considerably in excess of that used in spray irrigation, and will vary from 50,000 to 70,000 gallons per acre, the larger quantity being necessary for the light soils. For this reason it is doubly important in the interests of economy to have the water supply as near as possible to the land to be irrigated. Land intended to be irrigated by these methods must be level or only on a slight slope.

The Furrow Method. By this method, water is carried by pipes or pumped directly into ditches from which furrows run at right angles. The furrows are taken out in close proximity to the row crops to be watered and by making a breach in the side of the ditch with a spade or similar tool, the water flows into the furrow and seeps into the soil surrounding it. Irrigation of light soils by this method is seldom satisfactory because in order adequately to irrigate the land furthest from the furrow, the land near the furrow has to be over irrigated. The method is practised in this country only on a very limited scale, but is widely adopted in the Eastern States of the U.S.A. for crops of potatoes, sweet corn, beans, rhubarb, celery and fruit. (50).

IRRIGATION IN GLASSHOUSES

The essential difference between methods of watering plants under glass and plants growing out of doors is that the greater value of the glasshouse crops justifies more individual attention to them. Most glasshouse plants are watered individually at some stage in their lives, especially when they are in pots. With certain kinds the times vary at which different plants in the same batch require water, and the application of water to a batch of such plants collectively may easily lead to under or over watering of a proportion of them. If water is withheld because some of the plants do not require it, the others will suffer as a result. With an overhead irrigation system, unfortunately, there can be no individual discrimination, and consequently its use for certain systems of glasshouse culture must be limited. Overhead irrigation can be applied with advantage to crops which require a moist atmosphere and plenty of water at the roots, notable examples being cucumbers, orchids and forced bulbs. The early lettuce crop under glass usually does well under this system. For example, in the East Riding of Yorkshire, overhead watering on the spray-line system is practised on lettuce and tomatoes in unheated glasshouses of the Dutch type with marked success, both on heavy and light soils. With lettuce, certain varieties respond better to the system than others, a notable example being *May Queen*. This variety, planted in early January, will thrive with three or four heavy overhead waterings, amounting, inclusive of the base flooding before planting, to the equivalent of up to 10 in. of rain. In addition to this, several light waterings are given in sunny periods to cool down the plants and prevent excessive transpiration (Fig. 13). *Botrytis* disease invariably takes a heavy toll if the lettuce are planted in the early winter in these unheated houses. Under this cold system, lettuce are succeeded by tomatoes in April, and the latter benefit from a regular overhead damping and an occasional heavy watering by the same system.

Even where the hose is still preferred for the base watering, overhead spray lines provide a quick and labour saving method of damping down in hot sunny periods and for the spraying of tomatoes to assist pollination, but the capital outlay is comparatively high, i.e., installing them just for this purpose may not be economic.

The nozzles used in glasshouse irrigation are generally of two clearly defined types. One is designed to produce a finely diffused jet of water, and the nozzles are spaced at about 2-ft. intervals on the line. They have a comparatively low output of water and work best at a high pressure. The other, called the "mushroom" type, is of Dutch origin and throws a flat circular jet of water of greater volume but lower pressure and is spaced at about 6-ft. intervals on the line. These nozzles apply up to $2\frac{1}{2}$ in. of water per hour and therefore need a larger diameter pipe ($1\frac{1}{4}$ in. internal) than the first mentioned type. The circle watered by the mushroom nozzle is about 15 ft. in diameter at a pressure of 35 lb. per sq. in., and to ensure a complete "cover" the best results are obtained if one line is installed in each 9-ft. house (Dutch type). The mushroom lines are fixed with the nozzles in a vertical position, but if the diffuser nozzles are used, a smaller diameter pipe will suffice, which must, however, be oscillated in the usual way. A substantial saving of labour may be effected by the use of permanent spray lines in glasshouses, and in the case of a crop such as lettuce, paths, with their attendant "puddling" and wastage of space, can be dispensed with. Also there is complete freedom of mechanical injury to the plants. The use of a hose for some greenhouse crops invariably results in some damage to the stems of plants adjoining paths (e.g., tomatoes). It is not suggested, however, that the hose can be entirely dispensed with under all conditions.

On some nurseries, fine nozzles are used for the early growth of the crop and when its water requirements become greater, they may be replaced with little difficulty by coarser nozzles. The crop can be planted so that the spaces between the plants are in the line of throw of the nozzle; the plants will then not be deluged to the same extent as they would if the rows coincided with the nozzles. In such a case the line would have to be designed to "fit" the crop, i.e., so that the nozzles alternate with the plant rows. A house 30 ft. wide requires two lines if fitted with diffuser nozzles. The lines can turn on bearings fixed to the purlin posts; alternatively they can rest across the purlins, or be slung from them, the nozzles being directed downwards on to the crop. With crops which are trained close to the spans, such as cucumbers, it is necessary to erect the lines much nearer to soil level. Small propagating houses can have a single line slung from the ridge board, with diffuser nozzles directed downwards, the line being oscillated in the usual way.

Where small plants or seedlings are being watered by this method it is advantageous to be able to drain the water from the spray line immediately after the valve has been turned off, otherwise the drip, which continues for several minutes even from the smallest lines, is apt to cause damage. The drainage can be effected by sloping the line slightly and fixing a tap, or preferably a drainage pipe (of same diameter), at the lower end. This pipe is provided with a valve which can be opened immediately the spray-line valve is closed. The water left in the line then quickly drains away through this pipe, and an added advantage is the resultant suction of air through the nozzles that clears them of any debris which might have collected round them inside the pipe.

Watering by Hose. This is the method practised in most glasshouses. A rubber hose is connected to a tap and water is passed through the hose the other end of which is held close to the soil to be watered, in order to avoid splashing the plants. (A "rose" is seldom used for watering the base soil.) If the water splashes on to the plants, the crop may be marked, and there is a danger of disease infection. Dr. W. F. Bewley (in Bulletin 77, Tomatoes) says that "probably more trouble is due to the careless and injudicious use of the hose than to any other cause." When using a hose, it is worth bearing in mind that the loss of head due to friction of the water running through it is generally greater than that in a metal pipe of corresponding size, and long hoses of small diameter act as brakes to the flow of water from taps and stand-pipes. The water pressure at the distal end must not be too great, and if therefore a large quantity of water is required, the diameter of the hose must be comparatively large, i.e., $1\frac{1}{4}$ to $1\frac{1}{2}$ in. When watering tomatoes it is customary to lay the hose on the soil and leave it running so that an area of soil around it becomes flooded. The hose end is then moved to another position, and so on. It is important to ensure that the surface water applied makes contact with subsoil moisture. If a dry layer is left between the surface soil and the subsoil, bad results will ensue. A summer watering may vary from 5 to 10 gal. per sq. yd., but the winter "flooding" is substantially heavier than this. Correct temperature of the water must be maintained.

Porous hose has been used for watering rowcrops with some success. It emits the water throughout its entire length in the form of a slow trickle.

SUB-SOIL IRRIGATION

By this method water is applied direct to the roots of plants by means of a network of perforated or porous pipes or ducts, laid under the soil surface.

One system used in glasshouses consists in running water from a tap or hose into a concrete trough about 9 in. wide, the top of the sides of which are at soil level and the base about 8-9 in. below soil level. Porous pipes (2 in.) are connected with the side of the trough at its base at right angles on either side. The porous pipes are spaced at about 4 ft. apart but spacing will depend on the texture of the soil and the ease with which water can percolate through it.

Water is run into the trough at a sufficiently rapid rate to cover all the pipe outlets, and is only stopped when an examination of the soil indicates that sufficient has been applied.

The surface of the ground should preferably be level or at least have a slight and uniform slope. The surface soil must be open and porous and the sub-soil of close texture so that the water is retained in the root zone of the plants. If the sub-soil is open in texture the water will drain through it with practically no lateral movement. Larger quantities of water are required for this than for the other methods, and where it has been used in this country, it has not proved a success.

Soiless Cultivation. In the U.S.A. considerable research has been carried out on the soiless cultivation of plants. In the main there are three types of culture: liquid, sand, and sub-irrigation, of which the latter appears to be the most promising for commercial application. The plants are grown in

a waterproofed tank filled with a porous rooting medium such as gravel or cinders, the tank being provided with an inlet pipe at the bottom. The nutritional requirements of the plants are provided by a nutrient solution held in a separate tank at a lower level, and this is pumped up into the plant tank at intervals and allowed to flow back into the supply tank (43). Advantages claimed are control of water supply and nutrition, freedom from soil-borne diseases, and economy in labour and fertilizers. In this country, carnations under glass have responded satisfactorily to this method.

A drawback of these systems, particularly the sub-irrigation system, is that there is considerable risk of a disease spreading once it becomes established. It is questionable whether soilless cultivation is a commercial proposition in this country except, perhaps, for carnations.

Chapter V. DESIGN OF SPRAY IRRIGATION PLANTS

Spraylines of varying capacity have been manufactured in this country for many years, and can be relied upon to give excellent results, but the following notes are intended for those who may consider designing their own plants.

As already mentioned, the exact lay-out cannot be determined until certain factors are known, chief of which is the "coefficient of discharge" of the nozzles to be used. This is calculated by dividing the figure for the number of gallons per minute discharged through the aperture, by the square root of the pressure measured in feet of water. In this bulletin it is represented by "B", i.e., $B = \frac{q}{\sqrt{p}}$

where q = the number of gallons per minute discharged, and p = the pressure in feet of water. Certain other factors can be held constant, and Table VII shows the essential data required. The factors which can be regarded as constant at one value, or a small range of values, are:

Size of Nozzle Aperture

Spacing of Nozzles

Length of Lateral

Diameter of Lateral. 1 inch is taken as the most satisfactory size for lengths up to 250 ft. It represents a compromise between cost, ease of carrying, and evenness of distribution of water along the lateral. For lines exceeding 250 ft., more even distribution can be obtained by using larger diameter piping.

Pressure at Stand Pipe. The tables are worked out for a pressure of 43 lb. per sq. in. (100 ft. head) at the point where the lateral leaves the main.

Pressure Variation in the Lateral. Whatever the length of the nozzle line, and whatever the pressure maybe at the stand pipe, there must be a variation in discharge along it, and for all practical purposes the variation in discharge along the lateral equals approximately half that of the variation in pressure. In Table VII, the figures under P in column 3 represent the pressure at the stand pipe divided by the pressure at the distal (far) end. Thus if $P = 1.24$, the pressure in the lateral near the stand pipe is 24 per cent greater than at the distal end, and the discharge from nozzles at the stand pipe end is approximately 12 per cent greater than that from nozzles at the far end. To avoid unnecessarily large variations in the discharge through a lateral, it is therefore advisable when designing a system to select the conditions which will maintain as even a distribution of water as is practicable.

Total Discharge from Lateral. In order to determine the size of pump required, it is essential to know the total quantity of water discharged in a given time, and this is shown in columns 4 and 5 in cubic feet per second and gallons per minute. Column 6 shows the depth of irrigation water in inches per hour, and is based on the even application of water to a 40-ft. strip of land (i.e., 20 ft. on each side of the lateral) for the length indicated in column 2. For a different spacing, column 6 values can be easily modified, e.g., at 36-ft. spacing, the column 6 value should be multiplied by $\frac{40}{36}$ to give the rate of application.

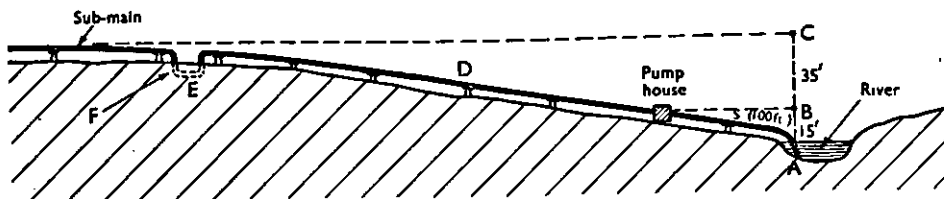


DIAGRAM 6. Irrigation scheme in section.

Example of Use of the Tables. It is desired to irrigate 20 acres of fairly level land from a river running about 1,000 ft. from the edge of the field, which measures roughly 300 × 320 yards, the highest point being 50 ft. above the level of the river bed. A variation of not more than 10 per cent is required in the quantity of water applied to the land, the available spray lines being 1 in. internal diameter.

Diagram 6 shows part of the scheme in section. For convenience the pump must be situated 15 ft. above the level of the river bed and a 100-ft. suction pipe will be necessary. The static pressure head will then be 50 — 15 = 35 ft. and the static suction head 15 ft. The furthest stand pipe will be approximately 2,000 ft. from the pump. It is desired to irrigate the whole field over a period of 7 to 10 days to a depth of about 1 in. This will allow from 1 to 1½ acres to be irrigated at a time, if each of two batteries of lines is used once daily, the first being re-erected ready for the next day's watering (see plan in Diagram 7).

To have one central main would mean having laterals of over 450 ft. but as it is desired to use laterals of 1-in. internal diameter, it is obviously necessary to have more than one main, or the laterals would be too long and very uneven watering would result. Two mains will allow four lengths of 240 ft. which is a convenient length for the lateral. To allow for entry of implements, etc., to the end of the field nearest to the river it would be advisable to have underground connexions between the delivery pipe and the two sub-mains. These would have to be provided with an easily accessible drain cock at the lowest point. All other mains and sub-mains can be above-ground, in which case cultivation will mostly have to be in two directions—AB and DC. To allow for irregularities in the boundary of the field, one main will have to be 936 ft. and the other 864 ft. in length, and assuming that the spray lines will be spaced at 36 ft., the number of valves required will then be 26 and 24 respectively. A 240-ft. lateral with an 18-ft. throw will cover about 1,000 sq. yds., i.e., six will cover about 1½ acres. This will involve the use of 12 laterals, six being erected while six are in use. The land on either side of the sub-main can be served in one operation by fitting 1½-in. branch tees carrying two 1¼-in. valves, which should run parallel with the sub-main.

Reference to Table VII indicates that for $B = .0147$, a 240-ft. lateral of 1-in. internal diameter will discharge 16 gal. per minute at 100-ft. pressure, with nozzles 2 ft. apart. Over a width of 36 ft. this represents .21 in. per hour (i.e., $0.19 \times \frac{40}{36}$).

Assuming that a pressure variation of not more than 20 per cent from one end of the pipe to the other is required, this spray line will not be satisfactory because the variation in pressure between stand pipe and distal ends is 32 per cent, i.e., the variation in discharge is 16 per cent. Table VII indicates that for $B = .01$, a similar line has a pressure variation of approximately only 16 per cent, i.e., a variation in discharge of only 8 per cent the total discharge being approximately $11\frac{1}{2}$ gal. per minute or .15 in. per hour (approx.). Thus to apply an inch of water, the second system would have to be run about 7 hours instead of 5 hours, although the water would be applied more evenly and slowly. The extra cost involved in running the plant for the longer period would be partly counter-balanced by the reduction in head through less friction in the mains as only about 70 gal. per min. would be passing through, compared with 100 gal. This is assuming, of course, that the stand pipe pressure is maintained at the 100 ft. (43 lb.). If that pressure is altered, then a different set of conditions arises, and by simple calculation, columns 5 and 6 can be altered for a different stand pipe pressure.

If there is no choice in the size of the nozzle, then the design must be altered to fit the given nozzle size.

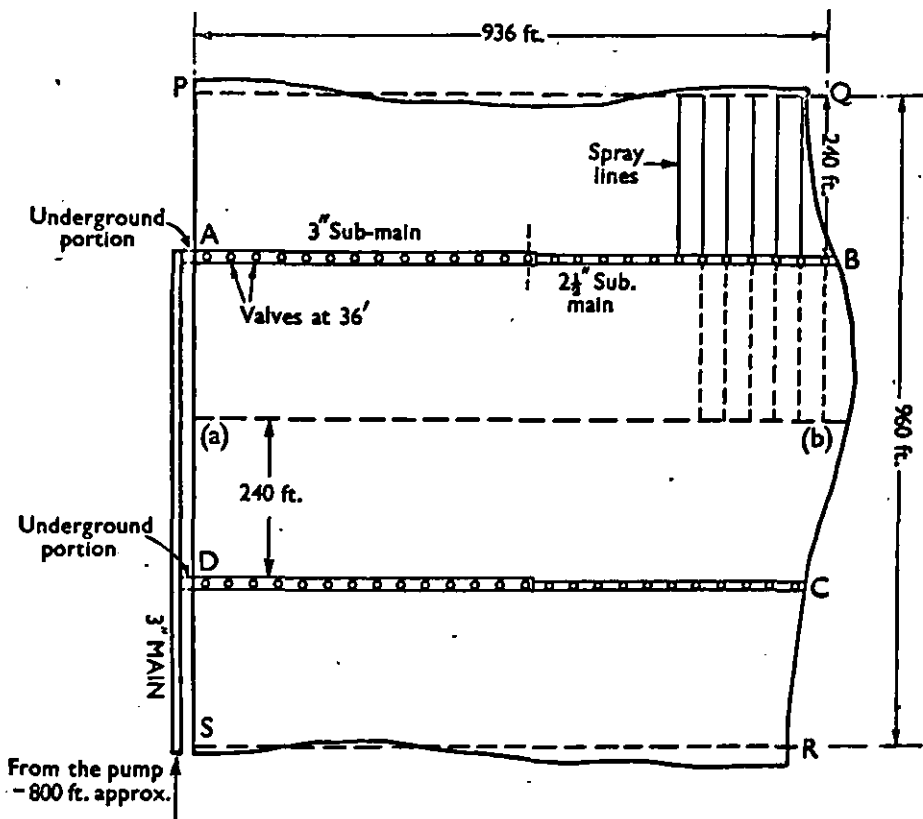


DIAGRAM 7. Irrigation scheme in plan.

Calculation of Necessary Horse-power, and Dimensions of Mains.
 Assuming that a flow of roughly 75 gal.* per min. is required with a minimum stand pipe (discharge) pressure of 100 ft., a reference to Table IV indicates that the friction head in 2,000 ft. of 2½-in. piping with a flow of 75 g.p.m. is 159 ft

* The actual quantity is 70 gal., but 75 is chosen for convenience in use of Table IV.

3-in. piping, the friction head is much less, i.e., 64 ft. So in order to economize in power, 3-in. piping is used. The total head is therefore made up as follows :

	<i>feet</i>
Static suction	15
" pressure	35
Friction head in suction pipe ...	3
" " discharge pipe ...	64
Discharge pressure (43 lb.) ...	100
Total	217

If a 2½-in. main is used the total head would be 312 ft. If the power unit is an internal combustion engine with an efficiency of 50 per cent and the pump is a centrifugal one with an efficiency of 70 per cent the required horse power will be $\frac{217 \times 75}{3,300} \times \frac{100}{70} \times \frac{100}{50} = 14$. (A reference to Table VI indicates that with an overall efficiency of 30 per cent. the required H.P. would be 16.) If an electric motor with an efficiency of 90 per cent is used, the required H.P. would be 7.8.

To economize in the cost of piping, about half the sub-mains could be reduced to 2½ in. but more power would be required. For instance, if the last 400 ft. of the sub-main is of 2½-in. pipe, the total head at its maximum, will then be

	<i>feet</i>
Static suction and pressure ...	50
Friction in suction pipe	3
" " discharge pipe	
1,600 ft. of 3 in. $16 \times 3.18 = 51$	51
400 ft. of 2½ in. $4 \times 7.93 = 32$	83
Discharge	100
Total	236

The required power would then be $\frac{236 \times 100}{3,300} \times \frac{100}{35} = 20.4$.

The extra friction head in the right-angle bends is not allowed for, but the greater the radius of any bends, the less is the head absorbed. The total head absorbed is substantially less when the battery is in use at the end of the field nearest the river, than when it is used at the far end.

If the grower is prepared to accept a greater variation in watering, he can dispense with one main and have a single central main (a b) with spray lines 480 ft. long on either side ; their internal diameter should start at 1½ in., reducing about midway to 1 in. for economy. (Even then the watering will be less uniform than with the shorter lengths of 1-in. line, or with the full length of 1½-in. line.)

Variation of Certain Factors. If it is desired to vary one or more factors Table VII can be used as follows :

(1) **PRESSURE AT STAND PIPE.** It may be necessary to use a different pressure than 100 ft. at the main, when the following equation holds.

$Q \propto \sqrt{P}$, (the equation is not accurate, but is a close approximation), where Q = total quantity of water discharged from the lateral in unit time. If, for instance, a head of 80 ft. is required, the figures in columns 4, 5 and 6 should be multiplied by $\frac{\sqrt{80}}{\sqrt{100}} = 0.89$. Columns 1, 2, and 3 would not be altered.

(2) **DIAMETER OF LATERALS.** Table VII is calculated for 1-in. laterals. For laterals of some other diameter, approximating to 1 in., the table can be modified to make it applicable. For instance, if a $1\frac{1}{4}$ -in. pipe were used instead of 1 in., by multiplying the figure for B by 1.817, and multiplying the figures in columns 4, 5 and 6, by 1.817, the tables can be used for $1\frac{1}{4}$ -in. pipes. Columns 2 and 3 remain unaltered (see Table V).

(3) **APERTURE SIZE.** For a fixed diameter of the pipe, alterations can be made to the Tables to allow for changes in the size of the aperture, i.e., for other values of B. When P and the diameter of the lateral are fixed, $Q \propto B^{0.351}$ and $X \propto B^{-0.649}$, X being the length of the lateral. Thus if the figure for B in the table is changed from 0.007 to 0.009, then the table can be adapted by multiplying column 2 of the rows corresponding to $B = 0.007$ by $\left(\frac{0.007}{0.009}\right)^{0.649}$ and multiplying columns 4 and 5 by $\left(\frac{0.009}{0.007}\right)^{0.351}$. Column 3 will remain unchanged and column 6 can be calculated from the area irrigated and the total quantity of water discharged.

(4) **SPACING OF NOZZLES.** Table VII is calculated for spray lines with nozzles spaced at 2-ft. intervals, as this is the commonest spacing practised in this country. For any other spacing, columns 2 to 6 can remain unaltered, but the coefficient of discharge would have to be altered proportionately, i.e., the value of B in column 1. Thus if it is required to space the nozzles at 3 ft. apart instead of 2 ft., the figures for the coefficient in column 1 would be multiplied by $\frac{3}{2}$. Alternatively, if nozzles are available with an aperture, the coefficient of which does not correspond with those in the tables, the spacing can be altered so that the total discharge corresponds to the figures in the tables. For instance, if nozzles with a value of $B = 0.02$ are required to be used, for rates of application as in Table VII (d), the spacing would be altered to $24 \times \frac{0.02}{0.0184}$ in. = 26 in. Table VII should suit the majority of cases met with in practice, but it could be changed to alter more than one constant.

TABLE I. RAINFALL IN MILLIMETRES,* MAY—AUGUST, IN S.E. ENGLAND.

	MAY						JUNE					
	First year of record	Average for month	Highest recorded		Lowest recorded		Average for month	Highest recorded		Lowest recorded		
			m.m.	Year	m.m.	Year		m.m.	Year	m.m.	Year	
London	1856	44	106	1856	4	1896	55	183	1903	1	1925	
Croydon	1921	47	103	1932	11	1936 1944	54	90	1926	4	1925	
Thorney Island	1881	42	106	1932	3	1936	46	100	1905	0	1925	
Lympne	1920	40	108	1930	14	1936	49	113	1927	1	1921	
Shoeburyness	1920	33	79	1924	9	1936	45	70	1937	5	1921	
Gorleston	1871	44	99	1924	3	1940	45	116	1927	5	1932	
Cranwell	1917	46	117	1932	13	1934	43	81	1936	3	1925	
	JULY						AUGUST					
London		55	124	1880	4	1921	57	165	1878	2	1940	
Croydon		60	105	1936	3	1921	59	106	1931	0.5	1940	
Thorney Island		53	132	1920	6	1905	57	149	1912	0	1940	
Lympne		54	126	1927	6	1935	59	129	1941	2	1940	
Shoeburyness		47	90	1940	7	1921	45	93	1941	4	1940	
Gorleston		59	150	1875	7	1897	63	208	1912	7	1937	
Cranwell		59	251	1932	10	1921	69	99	1917	11	1937 1940	

From Meteorological Office, Monthly Supplement.

* 1 inch = 2.54 c.m. = 25.4 m.m.

TABLE II. ESTIMATED MONTHLY TRANSPIRATION FROM GRASS LAND (IN INCHES) INCLUSIVE OF ANY LOSS OF MOISTURE BY EVAPORATION.

Month	Site		
	Rothamsted (Herts)	Lympne (Kent)	Shoeburyness (Essex)
January	0.1	0.1	
February	0.3	0.4	
March	1.1	1.2	1.2
April...	1.6	2.1	2.0
May ...	2.9	3.3	3.1
June ...	3.6	4.0	3.6
July ...	3.4	3.7	3.6
August	3.0	3.2	
September	1.5	1.6	
October	0.6	0.8	
November	0.1	0.2	
December	0.0	0.0	
Full year	18.2	20.6	

TABLE III. USEFUL DATA REGARDING WATER.

One Imperial gallon of water	= 1.2 U.S. gallon.
	= 0.16 cubic feet.
	= 10 lb. at 62° F.
	= 4.54 litres.
One cubic foot	= 6.25 Imperial gallons.
	= 7.48 U.S. gallons.
	= 62.5 lb. at 62° F.
One pound	= 0.016 cubic feet.
	= 27.7 cubic inches.
One litre	= 0.22 Imperial gallons.
	= 0.264 U.S. gallons.
One foot in height	= 0.433 lb. pressure per sq. in.
One pound pressure per square inch	= 2.31 ft. in height.
One horse power	= 33,000 foot-pounds per minute.
One acre inch of water per acre	= 101.28 tons.
	= 3,630 cubic feet.
	= 22,622 Imperial gallons.
	= 27,152 U.S. gallons.
	= 4½ Imperial gallons per sq. yd.
	= 374.1 gal. per minute.
One ton of water	= 224 Imperial gallons.
	= 35.943 cubic feet.

Between 40°F. and 212° F., water expands about 4 per cent in bulk.

TABLE IV. SHOWING APPROXIMATE LOSS OF HEAD IN FEET DUE TO PASSING WATER THROUGH 100 FT. OF IRON PIPING.

Gallons per Minute	Inside Diameter of Pipes in inches									
	$\frac{3}{4}$ in.	1 in.	$1\frac{1}{4}$ in.	$1\frac{1}{2}$ in.	2 in.	$2\frac{1}{2}$ in.	3 in.	4 in.	5 in.	6 in.
5	14.3	3.4	1.13	.45	.10	—	—	—	—	—
6	20.6	4.9	1.62	.65	.15	—	—	—	—	—
8	36.6	8.7	2.88	1.20	.27	—	—	—	—	—
10	—	13.7	4.49	1.80	.42	—	—	—	—	—
15	—	30.6	10.09	4.50	1.06	—	—	—	—	—
20	—	—	17.94	7.22	1.71	—	—	—	—	—
25	—	—	28.29	11.73	2.78	—	—	—	—	—
30	—	—	40.29	16.25	3.85	1.26	—	—	—	—
35	—	—	—	22.57	5.34	1.75	—	—	—	—
40	—	—	—	28.89	6.83	2.24	—	—	—	—
45	—	—	—	36.94	8.76	2.87	—	—	—	—
50	—	—	—	45.00	10.69	3.51	1.41	0.34	—	—
75	—	—	—	112.00	26.67	7.93	3.18	0.72	—	—
100	—	—	—	180.00	42.66	14.00	5.63	1.33	—	—
125	—	—	—	—	69.49	22.00	8.80	2.17	—	—
150	—	—	—	—	96.32	31.59	12.70	3.01	—	—
175	—	—	—	—	130.90	43.02	17.23	4.18	—	—
200	—	—	—	—	171.30	56.16	22.56	5.35	1.75	.70
250	—	—	—	—	—	87.60	35.26	8.36	2.74	1.10
300	—	—	—	—	—	126.30	50.79	12.05	3.94	1.58
350	—	—	—	—	—	—	69.15	16.40	5.37	2.15
400	—	—	—	—	—	—	90.32	21.43	6.99	2.81
450	—	—	—	—	—	—	114.32	27.09	8.87	3.56
500	—	—	—	—	—	—	140.98	33.46	10.95	4.40
750	—	—	—	—	—	—	—	—	—	9.90
1,000	—	—	—	—	—	—	—	—	—	17.63

NOTE. These figures are not applicable to nozzle lines, but only to plain piping.

TABLE V. EFFECT ON B (COEFFICIENT OF DISCHARGE) AND Q (TOTAL WATER DISCHARGED) OF VARIATION IN DIAMETER OF SPRAY LINE, WHEN P AND LENGTH OF LINE ARE FIXED.

Diameter of Line (inches)	Factor for B and Q
$\frac{3}{8}$.462
$\frac{1}{2}$.669
1	1.000
$1\frac{1}{8}$	1.372
$1\frac{1}{4}$	1.817
$1\frac{3}{8}$	2.386
$1\frac{1}{2}$	2.960
$1\frac{3}{4}$	4.48
2	6.41

The figures for B and Q are relative to those for a 1-inch spray line.

TABLE VI. SAFE HORSE POWER OF INTERNAL COMBUSTION ENGINES TO PUMP WATER AGAINST TOTAL HEAD FOR ALL CAUSES, (i.e. SUCTION LIFT, DELIVERY HEAD, VALVES, PIPING, BENDS INCLUDED) FROM 30 FT. TO 200 FT. OVERALL EFFICIENCY, ENGINE AND PUMP, BEING 30 PER CENT.

Imperial gallons per minute	Gallons per hour	Total head in feet												
		30	40	50	60	70	80	90	100	120	140	160	180	200
5	300	.12	.24	.24	.36	.36	.48	.48	.48	.60	.72	.84	.96	.96
10	600	.36	.36	.48	.60	.72	.84	.96	.96	1.20	1.44	1.68	1.80	2.04
15	900	.48	.60	.72	.96	1.08	1.20	1.32	1.56	1.80	2.16	2.40	2.76	3.00
20	1,200	.60	.84	.96	1.20	1.44	1.68	1.80	2.04	2.40	2.88	3.24	3.60	4.08
25	1,500	.72	.96	1.32	1.56	1.80	2.04	2.28	2.52	3.00	3.60	4.08	4.56	5.04
30	1,800	.96	1.20	1.56	1.80	2.16	2.40	2.76	3.00	3.60	4.20	4.80	5.52	6.12
35	2,100	1.08	1.44	1.80	2.16	2.52	2.88	3.24	3.60	4.20	4.92	5.64	6.36	7.08
40	2,400	1.20	1.68	2.04	2.40	2.88	3.24	3.60	4.08	4.80	5.64	6.48	7.32	8.04
45	2,700	1.32	1.80	2.28	2.76	3.24	3.60	4.08	4.56	5.52	6.36	7.32	8.16	9.12
50	3,000	1.56	2.04	2.52	3.00	3.60	4.08	4.56	5.04	6.12	7.08	8.04	9.12	10.08
60	3,600	1.80	2.40	3.00	3.60	4.20	4.80	5.52	6.12	7.32	8.52	9.72	10.92	12.12
70	4,200	2.16	2.88	3.60	4.20	4.92	5.64	6.36	7.08	8.52	9.96	11.28	12.72	14.16
80	4,800	2.40	3.24	4.08	4.92	5.64	6.48	7.32	8.04	9.72	11.28	12.96	14.52	16.20
90	5,400	2.76	3.60	4.56	5.52	6.36	7.32	8.16	9.12	10.92	12.72	14.52	16.44	18.24
100	6,000	3.00	4.08	5.04	6.00	7.08	8.04	9.12	10.08	12.12	14.16	16.20	18.24	20.28

NOTE. This table will hold good as a guide only for most types of pumps, but manufacturers can give figures to suit their own products, which may be taken as more efficient than above.

TABLE VII. DISCHARGE AND FALL IN PRESSURE ALONG 1 IN. SPRAY LINES, WITH A 100-FT. HEAD AT THE MAIN. NOZZLES 2 FT. APART.

1	2	3	4	5	6	
Coefficient of discharge of nozzle (B)	Length of spray line (feet)	(P) (Pressure variation)	Total quantity discharged (Q)		Rate of Application over 40 ft. (inches per hour)	
			Cubic feet per second	Gallons per minute		
(a) .007	470	1.62	.03893	14.6	.089	
	439	1.50	.03737	14.0	.092	
	408	1.40	.03555	13.3	.094	
	376	1.32	.03356	12.6	.096	
	345	1.24	.03135	11.7	.098	
	314	1.19	.02904	10.9	.099	
	282	1.14	.02651	9.9	.10	
	251	1.10	.02397	9.0	.10	
	220	1.06	.02138	8.0	.11	
(b) .01	385	1.62	.0434	16.2	.12	
	360	1.50	.0416	15.6	.12	
	334	1.40	.0396	14.8	.13	
	308	1.32	.0374	14.0	.13	
	283	1.24	.0350	13.1	.13	
	257	1.19	.0323	12.1	.14	
	231	1.14	.0295	11.1	.14	
		205	1.10	.0267	10.0	.14
(c) .0147	300	1.62	.0496	18.6	.17	
	280	1.50	.0476	17.8	.18	
	260	1.40	.0453	16.9	.18	
	240	1.32	.0427	16.0	.19	
	220	1.24	.0400	15.0	.19	
	200	1.19	.0370	13.9	.20	
	180	1.14	.0338	12.7	.20	
		160	1.10	.0306	11.4	.21
(d) .0184	260	1.63	.0538	20.1	.22	
	240	1.49	.0512	19.2	.22	
	220	1.38	.0482	18.1	.23	
	200	1.28	.0450	16.9	.24	
	180	1.21	.0413	15.5	.25	
	160	1.15	.0375	14.1	.25	
	140	1.11	.0334	12.5	.26	
		120	1.07	.0292	11.0	.26
(e) .0257	220	1.74	.0615	23.0	.30	
	200	1.55	.0588	22.0	.32	
	180	1.40	.0549	20.6	.33	
	160	1.28	.0504	18.9	.34	
	140	1.19	.0453	17.0	.35	
	120	1.13	.0398	14.9	.35	
		100	1.08	.0339	12.7	.36

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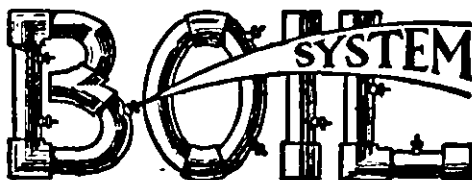
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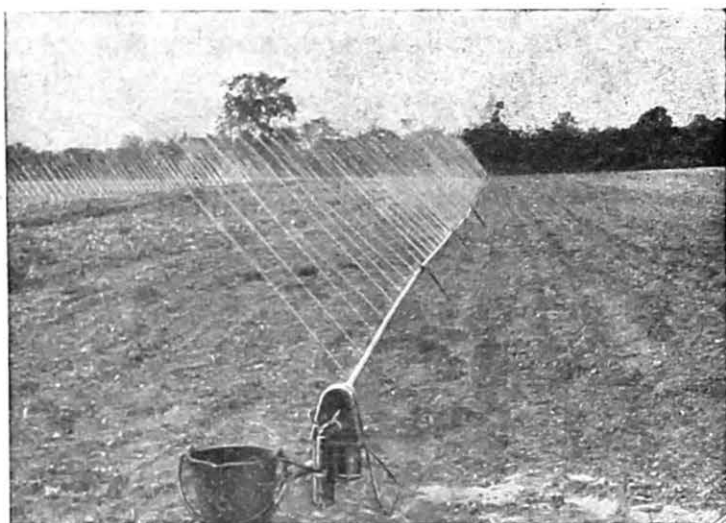
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