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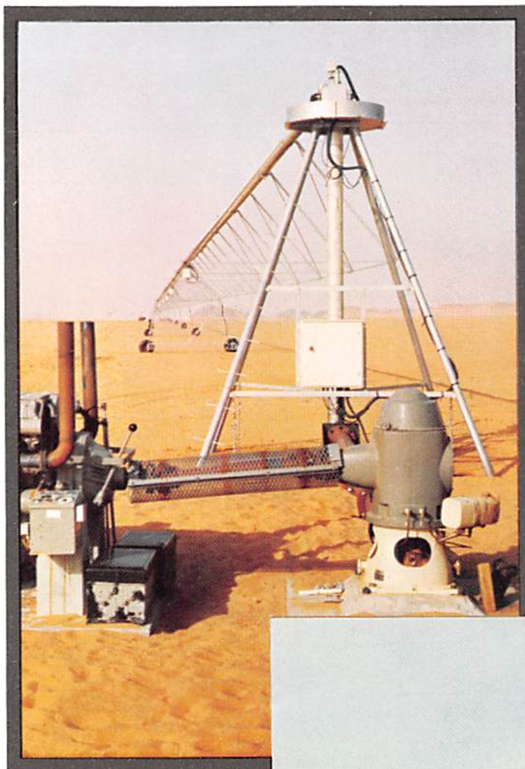

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GUEST EDITORIAL

Irrigation for Agriculture and Horticulture in the 70's

by J. Waterhouse*

IRRIGATION is a word meaning so many things depending on who you are and where you are, and it was good to have this brought out and emphasised many times during the course of the one day meeting at Silsoe. From the British farmer's side we heard that irrigation is just one of many factors in successful agriculture – and not a really important one at that. The horticulturist makes use of irrigation to save crops from frost damage, and the politician in the Far East sees irrigation as a means of keeping people busy on the land and keeping them away from cities.

Irrigation cannot stand alone. It relies at one end on the correct planning and development of water sources, both surface and groundwater. At the other end it must be carefully linked with drainage so that damage from undesirable water quantity and quality can be minimised. Somewhere in the middle is the possibility – often exploited – of utilising irrigation water to combat crop disease and to apply plant nutrients. The papers presented at the meeting and the subsequent discussions outlined a number of facets, each one of which deserves detailed consideration by way of research, development, practice, and analysis. There certainly would appear to be much to offer the aspiring young agricultural engineer in the irrigation field.

In England the development of water resources across regional boundaries should make it easier to ensure reliable supplies for agriculture, and indeed Dr Penman said that years ago the Water Resources Board accepted the case made out by agriculture for more water, the Board pledging itself to providing the necessary water. It is hoped that the new Regional Water Authorities will continue to give due regard to the demands of agriculture for adequate supplies of water and for the control of water on the land.

It is not easy to analyse the fluctuations of irrigation usage in Great Britain in recent years, nor to predict to what extent irrigation will continue or increase. As one author put it, who can tell what will be the market price of tomatoes ten years hence? Certainly there is a job to be done in assessing the past and probable future patterns for irrigation in all its forms, but by whom? Manufacturers stand to gain by such an analysis, and so do producers. The Ministry collect data and give advice, but is this sufficient without systematic collection of all relevant marginal information? One speaker called for a centre at which knowledge and experience on irrigation could be collected and disseminated to interested parties and to users. To what extent this would duplicate existing work would have to be discussed, but there is evidence that there are some slender threads between farmer, researcher, engineer, and contractor which need strengthening. We were reminded that research has, to date, provided a coarse means of identifying factors

pertinent to irrigation and that refinements are now being actively pursued; this second phase in research should result in further advances in knowledge and practice. It could be said, then, that this is an appropriate time to put in hand a system of integration for the whole field of irrigation, from river to sprinkler, from root growth to leaf water potential.

The International Commission on Irrigation and Drainage (*ICID*) has a British National Committee which reflects the large part played by British engineers in developing many grandiose schemes overseas, but which does not appear to give full cognisance to the more earthy agricultural matters which are vital to success in both drainage and irrigation. It is understood that steps now being taken will remedy this situation, and one hopes that the Institution and its members will be in a position to make a worthwhile contribution. In any event, curiosity, inventiveness, profit motives and the necessity to eat will see extensions to irrigation in many parts of the world for years to come.

**J. Waterhouse joined the National College of Agricultural Engineering in 1968. Previously, he had been concerned with civil engineering projects mainly in water supply and reclamation. As a civil engineer at NCAE his interests involve water resources within the broad spectrum of soil and water engineering.*

The Irrigation Policy, Practice and Economics of Two Companies Farming in Essex and Suffolk*

by J. A. Comyn MBE FCIS†

Summary

THIS paper is a case study of irrigation as practised on a particular group of farms. In the introduction it is suggested that irrigation is only one of the factors of production which the farmer and the horticulturalist have to master, hence an important aim of research and development should be to evolve simple and proven techniques. The two companies considered farm 8900 ha (22 000 acres). growing all the main agricultural crops and also peas and beans for processing. There are in addition 2300 cows and followers. Over the past 20 years their policy has been to extend the use of irrigation, mainly by the construction of winter storage reservoirs. Problems of water supply have now largely been solved, particularly as it seems that in the past the water requirements of some crops may have been over estimated, but problems of labour usage and of overground equipment remain. Priority for irrigation is given to potatoes and to grassland, and to the lighter soils. The companies are convinced that investment in irrigation provides a good return in spite of the high fixed costs of reservoir based schemes. For the future, they hope for improvements in equipment, for more information as to the true water requirements of crops, and for a greater co-ordination between the disciplines of soil science, land drainage and irrigation.

Introduction

It is fitting that the first paper in this symposium should be devoted to a case study of irrigation as developed and practised on a particular group of farms. As engineers, members of the Institution must primarily be interested in technical developments in the sphere; but the object of all research and of the development of engineering techniques in the field of irrigation is to enable the ordinary working farmer and horticulturalist to apply the right amounts of water, at the right time and at the right cost to those crops which will benefit. Irrigation is, moreover, only one of the many factors which the ordinary farmer has to take into account in optimising his returns. Equally important are correct cultivations, fertiliser and spray usage, adequate land drainage, efficient labour and machinery utilisation, and even making sure that cash discounts and *VAT* repayments are promptly collected. Amid so many problems of management the farmer looks to the scientist and to the agricultural engineering profession to develop irrigation recommendations and techniques which are simple to understand and operate and which, however theoretically impeccable, have been proved in the hard school of day to day farm operations. Research and the development of techniques must surely always keep this end in view. It is appropriate, therefore, that this first paper should give some description of the practice of irrigation on a microcosm of agriculture in the UK, in the shape of two companies under common management farming in the Eastern Counties, and should attempt to identify some of the problems which are encountered in this field.

Background

The two companies farm a total of 8900 ha (22 000 acres) of which approximately 1600 ha (4000 acres) are in Suffolk and 7300 ha (18 000 acres) in Essex. Although all the farms are in a low rainfall area (average under 53 cm [21 in] year) there are significant differences in average rainfall recorded, particularly between coastal and non-coastal farms. There are also considerable differences in soil type and hence in irrigation requirements. The cropping system is fairly consistent, the main crops grown on nearly all the farms being corn, potatoes, sugar beet, peas and beans. On the Essex farms peas and beans are mainly grown for processing. On nearly every farm some grass is required for cows and/or young stock, the total livestock population being 2300 cows and 2100 calves and heifers. In general it may be said that owing to the pattern of rainfall and potential transpiration in the area there is a need for irrigation on the lighter soils in nine years out of ten if maximum crop growth is to be assured.

Policy

Spray irrigation has been used on some of the farms for at least 20 years. Since 1960 the policy of the companies has been to expand its use, within the context of other demands on investment resources, in order to achieve the following benefits:

(a) Heavier and better quality crops, particularly of potatoes, sugar beet and grass.
(b) Timely preparation of seedbeds to ensure a succession of peas and beans to meet factory schedules.
(c) Reduction of the area of grassland required for livestock keep, thus enabling more land to be devoted to arable crops.
(d) To facilitate harvesting eg of potatoes, in a dry autumn.
(e) To assist in effluent disposal.

Practice

Apart from finance, the main constraints on irrigation are water supply and labour availability. Up to 1963 water supply was mainly

**Institution of Agricultural Engineers Autumn meeting, at NCAE, Silsoe, on 27 September 1973.*

†A director of Lord Rayleigh's Farms Inc. and of Strutt & Parker (Farms) Ltd.

by direct abstraction from rivers and streams, supplemented by a gravel pit with a capacity of 45 500 m^3 (59 500 yd^3). With the growing demand for irrigation, and in view of the restrictions on direct abstraction inherent in the 1963 Act, the policy of the two companies during the past ten years has been to build winter storage reservoirs. There are now the following reservoirs in operation.

	m^3	yd^3
Essex		
Leez reservoirs system	454 500	594 440
Bradwell-on-Sea area	50 000	65 400
Burnham-on-Crouch area	45 500	59 500
Suffolk		
Thorpe Morieux area	90 900	118 800

There is also the gravel pit mentioned earlier, and a lake in Suffolk with a potential of 55 000 m^3 (71 900 yd^3) per annum making a total stored water reserve of 741 000 m^3 (163 million gallons), enough to put one inch of water on 7200 acres or, in metric terms, 25 mm on 2960 hectares. In addition an average of 79 000 m^3 (103 300 yd^3) annually may be directly abstracted from streams under Licences of Right.

The licences held by the companies, with the exception of the licence to abstract from the lake in Suffolk, are controlled by the Essex River Authority.

It is a large Authority and perforce has had to adopt methods of working which sometimes may seem somewhat legalistic. In particular the charging system is immensely complicated. In the past this has caused some headaches to those members of our office staff who have had to deal with the large number of licences in operation, and the differentiations between charges for 'coastal' and 'non-coastal', 'all seasons', 'winter' and 'summer' abstractions, plus the various 'weighting factors' involved, together with 'Section 60 Agreements' and 'Section 63 Agreements', the latter being a form of two part tariff. Once we had got all this straight and converted to decimal currency everything was metricated, causing further headaches. Under the Essex River Authority charging system there is, at present, a standard charge of 9p per thousand cubic metres. This is adjusted by the 'weighting factor' just mentioned, depending on the source and season of the abstraction. In the case of abstraction to an artificial winter storage reservoir in a non-coastal area the cost works out at about 9p per acre/inch of licensed (not actual) abstraction. In the case of a direct summer abstraction from stream in the same area it will be 90p per acre/inch, a very considerable difference. I am aware that your Institution prefers metric terms, but the farmer still thinks in acre/inches, and I fear will do so for a long time to come! I have mentioned the complications of the *ERA* charging scheme because they are the sort of complications which farmers can well do without. On the other hand, the Essex River Authority has been most helpful and co-operative in every aspect of our development of irrigation. It has shown great efficiency and imagination in helping our two companies to achieve a situation in which water supply is no longer a limiting factor in our irrigation activities.

Turning to labour availability, the first constraint is the competition of other farm tasks at the times when irrigation is required. Little hay is made and usually enough labour for irrigation can be made available when necessary, except on certain farms during the height of the pea vining season ie July and if a heavy irrigation need coincides with the corn harvest. The second is the amount of labour required to move ground equipment, the requirement being very high with orthodox static layouts. This is a serious problem and there is a pressing need for improved labour saving equipment. At present the companies are experimenting with hydraulically propelled spray booms and may try giant static rotary equipment on suitable sites, particularly for the irrigation of grassland. However, many fields are irregularly shaped, or in other ways unsuited for large rotary machines. The third factor affecting labour is the sheer unpleasantness of moving pipe lines on saturated soil. This is quite a serious problem, although we have not yet been obliged, as have some farmers, to pay extra money for this job. In general it may be said that the companies have not as yet invested in sufficient ground equipment to make maximum use of the water available, in a very dry season, because they are unwilling to make too big an investment in types of equipment at present offered in case something better appears on the market.

Within these constraints it is the practice to irrigate, as first priorities, potatoes and grassland. Usually some sugar beet is watered in August/September after potato irrigation has ended. In a dry season up to 76 mm/0.40 ha (three inches per acre) have been used on potatoes. Particularly dramatic results have been achieved from irrigation of grass and root crops on a farm where the soil is so sandy that without irrigation it would be difficult to grow these crops at all. In general it is not the practice to provide irrigation of the heavier moisture retentive clays as it seems a better use of resources to concentrate on the lighter, brickearth soils.

When the reservoir irrigation schemes were planned the calculations of water requirement were naturally based on current crop acreages and rotations, together with the research and meteorological information then available. The aim was to provide adequate irrigation in the third driest year of a statistical ten year period. Over the years it has been found that the amount of water needed sometimes appears to have been over estimated, in the sense that even in a dry season actual application has invariably fallen short of the theoretical requirement. To an extent this has been due to limitations of labour and equipment, but there is some reason to think that with increased knowledge of crop response periods and of the apparent reduction of transpiration under water stress the original requirements may have been over assessed.

Storage of water is expensive, and such over assessment of need can lead to unnecessarily high fixed costs. This situation, where it has appeared, is gradually righting itself by an increased use of water on grassland, which has shown a greater economic return from irrigation than was assumed some years ago. There is also likely to be an increasing requirement for irrigation of vegetable crops for processing.

As the increasing use of irrigation on grassland has been mentioned, it may be interesting to note that the most recent irrigation scheme developed is at Thorpe Morieux in Suffolk, where a reservoir has been built at the same time as a new cow-house, mainly to provide irrigation for 70 acres of grassland to support the herd of 140 cows. Paddocks have been laid out conveniently to the cow-house and on a plan suitable for the functioning of hydraulically propelled spray boom units, thereby reducing the labour requirement to a minimum. Between each irrigation some 60 units of nitrogen compounded with five of phosphates and five of potash are applied per acre. This system only started to operate this year, but results to date have been most satisfactory, enough grazing having been provided from 20 ha (50 acres), and the remainder having been conserved as silage.

Something should be said as to the methods of assessing the irrigation need of crops in the context of our day to day farm management. Volumes have been written on this subject, and a number of devices, such as tensiometers, rain gauges, transpiration tables, jam tins and water balance sheets recommended to farmers. Many of these methods have proved too time consuming for practical use. A rain gauge is essential, together with some means of estimating the amount of irrigation water applied. The latter may be a meter (after due allowance for losses in leakages and in emptying pipes) or a time calculation, based on knowledge of the output of the equipment in use. Neither method is particularly accurate, but in practice either provides sufficient information for normal purposes. As regards the estimation of deficits, and judgement of the right time to irrigate, we are fortunate in Essex in having an excellent service from *ADAS*, which circulates a weekly postcard to irrigators showing the current rainfall, transpiration and deficit figures, at Writtle, in the case of grass and orchards and of potatoes and vegetables respectively. These figures, adjusted by local rainfall measurements, form an excellent guide to our managers and foremen and are used, in combination with their own observation, experience and judgement, in making the necessary decisions.

Economics

While it is feasible to calculate the cost of irrigation it is much more difficult to assess the returns in financial terms, except in controlled experiments on model farms. *ADAS* provide figures of increased output of various crops per acre/inch applied, but these can only be a general guide. Apart from increased output there may be unquantifiable benefits in timeliness, thereby obtaining a better price, in quality (eg the avoidance of scab in potatoes) and in ease of harvesting. Irrigation may prevent, in a bad drought period, the loss of a crop, and provide insurance that a limited area of grass will support a cow herd throughout the season as planned. There may, however, be losses due to irrigation, for instance the flooding of a crop due to heavy rain immediately following irrigation, the depression of sugar content in sugar beet or spoiling of irrigated potatoes under certain storage conditions. It has also been found that consistent irrigation shows up faults in old drainage systems, with consequent expense in redraining, an expense which, nevertheless, must be beneficial in the long run. The companies are at any rate convinced from objective and subjective evidence over the years that a carefully considered investment in irrigation produces a satisfactory return on capital.

The capital investment is very considerable where the main water source is reservoirs. Seventy percent of the cost of this type of irrigation is depreciation and interest on reservoirs, underground mains, pumps and ground equipment. This fixed cost has to be covered irrespective of the amount of irrigation applied each year, with its variable costs of labour and fuel/electricity for pumping. Accordingly the fixed costs of irrigation can be fairly assessed only over a period of years, in the context of fair estimates of wear and tear and obsolescence, and taking into account the likelihood of eventual sedimentation of reservoirs.

The Leez Reservoirs system, which is now in its seventh year of operation, and for which detailed costings are available for the six seasons since 1967, may be taken as an example of how fixed costs may be assessed. The net cost of this scheme after grant, including the two main reservoirs with a capacity of 454m l (100m gal), the two subsidiary reservoirs and about 16 km (ten miles) of underground mains, was £70 000. There was a further initial investment of £15 000 in pumps and overground equipment. The investment of £70 000 amortised over 25 years, at 8% compound interest, results in an annual charge of £6557. The investment of £15 000 in pumps and overground equipment, amortised over ten years at the same rate of interest, results in an annual charge of £2235. The total annual capital charges may therefore be assessed at £8792.

Another type of fixed cost is River Authority water charges, as these have to be paid on the quantity of water licensed to be abstracted, and not on the quantity actually used for irrigation (if a two part tariff is in operation this statement needs some qualification). There is some annual expenditure on maintenance and repair of reservoir banks, filling pumps etc which is not related to the quantity of water used for irrigation in any year. There is also a notional rent to be paid for the land on which the reservoirs stand. In the case of the Leez Reservoirs this amounts to 18.6 ha (46 acres) in all, representing a sizeable diversion of resources from agricultural production. Fortunately this cost is recouped in full by letting the irrigation lakes to a fishing club, which has over one hundred members and stocks the water with brown and rainbow trout.

It has been found that over the six seasons 1967–72 total fixed costs as calculated on the above lines have amounted to £55 175. In the same period the total irrigation used was 10 254 acre/inches, producing an average fixed cost per acre/inch of £5.38. This is higher than originally estimated, due largely to a degree of under-utilisation of available water. The reasons for this have already been discussed and it is likely that as utilisation increases the fixed cost per acre/inch will fall to about £4.00.

Variable costs over the period have averaged £2.05 per acre/inch. About £1.12 of this is labour, the balance representing electric power for the irrigation pumps, repairs and haulage. The total average cost per acre/inch has, therefore, been fixed costs £5.38, variable costs £2.05, total cost £7.43.

In 1969 *ADAS* estimated that the increased gross margins achieved from the system, per acre/inch of water applied, were £12 for potatoes, £7 for grass, £3 for sugar beet and £15 for dwarf beans. These figures are now outdated but tend to show that at an average total cost of £7.43 per acre/inch there is a good return on potatoes, which is the crop on which 40% of the irrigation is used, and that the other crops all cover their direct costs and make some contribution to overheads. In the years to come, with the higher product prices anticipated and only a marginal increase in total costs per acre/inch (due to the high proportion of pre-inflation fixed costs) the return should be increasingly rewarding.

The future

Looking to the future, we hope that technical progress will result in an extension of labour saving, reliable equipment which can work 24 hours a day. Attention must be paid to the size of droplet and accuracy of application. The tendency towards ever higher operating water pressures should be examined. Methods of conveniently applying fertilisers and disposing of effluents through irrigation systems should be improved. From the scientists more information is required as to the true water requirements of growing crops and as to the best way of satisfying these while conserving water resources and economising in the use of labour and equipment. The problems of irrigation and of land drainage are obviously closely linked. Is it too much to hope that the skills of the soil scientists, the land drainage experts and the irrigation engineers may not one day be combined in order to find a method of maintaining a soil/water balance which will be constantly attuned to the requirements of the growing crop? These are the kind of developments which the farmer expects from the experts constantly at work at Rothamsted, Wellesbourne and Hurley, from the equipment manufacturers, and from members of your Institution, all of whom have done so much in the past to develop irrigation science and techniques. It is an ancient skill with a long tradition, spanning the ages from the Pharaohs through the Persian Wheel and the 'drowners' of water meadows to the giant rotary irrigators of the present day. No doubt future developments will be even more sophisticated, more imaginative and more productive than those the world has already seen.

Water for Irrigation*

by R. Huntington BSc FICE FIWE FIPHE †

Synopsis

TO maintain optimum growth, plants require adequate water to sustain full transpiration and when nature does not provide enough rainfall the deficit needs to be made good by artificial means. Various methods of obtaining irrigation water from surface and underground sources are considered. River authorities have to ensure that no new licence derogates from the rights of existing abstractors and the implications of this for would-be irrigators in areas of high demand are discussed.

Comments are made regarding means of making the best use of available sources, taking full account of their hydrological and geological characteristics. In this respect the benefits of early technical consultation with the river authority are stressed.

The amount of irrigation water which is returned to resources in years of varying dryness and with different irrigation treatments is examined. Finally, the economics of irrigation are discussed with particular reference to the cost of obtaining water and the effects of postulated future trends in abstraction charges.

Introduction

Figures are frequently quoted giving the quantity of water used for public supply and the still larger quantities used for industrial purposes. However, it is seldom appreciated that these amounts are dwarfed by the quantities used for agriculture – not licensed abstractions but water returned to the atmosphere by transpiration from vegetation. In fact, for England and Wales this quantity is about 7×10^{10} m^3 (8.4×10^{10} yd^3) each year; roughly 14 times the total used for public supply. It is estimated that each tonne of potatoes and cereals harvested will have evaporated over 100 and 700 tonnes of water respectively during their growing season. Furthermore, whilst a substantial percentage of the water used for industrial and public supplies is returned to resources, evapotranspiration is a complete loss. In consequence only a small percentage of rainfall finds its way into the streams and rivers as run-off or infiltrates into ground water aquifers. To give scale to this the average annual rainfall in the Essex River Authority area totals 600 mm (23.6 in) whilst plant transpiration and evaporation losses amount to 450 mm (17.7 in), leaving only 150 mm (6 in) 'effective' precipitation (ie actual input to resources). Infiltration to the groundwater aquifers accounts for perhaps 30 mm (1.2 in) with the remaining 120 mm (4.7 in) running off in the rivers. These small amounts are susceptible to droughts and in a dry year rainfall only 20% below average can produce a run-off 60% below average.

For good growth, plants require a certain amount of water to maintain satisfactory transpiration and only when nature does not provide sufficient moisture is irrigation required to make up the difference. Assessment of irrigation needs is therefore concerned with calculating the likely difference between the quantity of water required by plants and the amount provided by nature. In the south-east of the country there would appear to be an irrigation requirement ranging from five years in ten in the wetter part, to over nine years in ten in the extreme south and east.

Water requirement

This paper is not concerned with the detailed design of irrigation schemes, but only with the provision of water to meet irrigation requirements. However, before this matter can be tackled, brief mention must be made of the earlier steps which need to be taken, once a decision to irrigate has been made.

These are:

(a) Decide what crop or crops are to be irrigated and their acreages.

(b) Decide the design basis for water need ie whether the full water requirements shall be provided to meet the needs of say the driest, second or third driest year in ten.

Economics will play a major part in deciding these choices, particularly if the construction of surface storage is likely to be involved. Having decided these fundamental matters, straightforward calculations will enable the hourly, daily, monthly and seasonal water quantities to be assessed using standard procedures set out in the *MAFF* Bulletins[1 2 3 4]

Water sources available

The next stage covers the investigation of sources available to meet the calculated needs and it is possible that on completion of this part of the exercise limited water availability may necessitate a re-examination of the irrigation plan. While public supply is used to a limited extent for some crops, particularly those grown under glass, its cost in a majority of cases may be uneconomic and reliance may have to be placed on the cheaper private abstractions from surface or groundwater. In both cases water quality must be adequate for the particular crop to be irrigated. In some areas groundwater may be too saline, while some surface waters may contain chemicals which may affect plant growth; professional advice should be sought if in any doubt.

Surface sources

Irrigation need and availability tend to form a vicious circle; water is least available when it is most needed – ie in mid-summer and, of course, particularly in drier years. Furthermore, those areas with a naturally low run-off have the greatest irrigation need.

Average annual rainfall is approximately evenly divided between winter and summer but high transpiration in the latter period results in a very much lower surface run-off eg in large areas of the south-east run-off in an average mid-summer is less than six percent of the rainfall compared with nearly 50% in mid-winter. Inevitably this leads to water availability difficulties, particularly in view of the fact that irrigation requires relatively large rates of abstraction over limited periods.

An indication of the size of the problem can be obtained by considering catchments in Essex and Suffolk. The average run-off in the three months June to August is about 3 mm (0.12 in) per month. At these flows a standard 0.4 ha (one acre) irrigation set putting on 25 mm (one inch) of water in three hours requires a catchment of 9.7 km^2 (3.78 miles^2) to support it, and in a dry year more than 20 km^2 (7.7 miles^2). In a number of catchments the area per irrigator ranges between 10 and 18 km^2 (3.9 and 6.9 miles^2) ie irrigation abstractions alone could dry up some rivers and leave no water for other uses, including amenity. While it is appreciated that all may not wish to irrigate at the same time, and that the distribution of abstractors is uneven, nevertheless it does illustrate the serious depletion in resources which can result from direct summer abstractions.

In the drier areas of the country sufficient water is no longer available to meet the full direct abstraction demand and to meet requirements water must be stored during winter high flow periods for subsequent use in the summer. Even so, in some catchments the stage has been reached where in severe droughts winter flows are inadequate to meet full water requirements. On catchments where it is necessary to construct storage reservoirs with a stream or river as the source, some form of control works will usually be necessary to ensure adequate downstream flows are maintained to meet legitimate requirements. Particularly where storage has been

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Institution of Agricultural Engineers Autumn meeting, at NCAE, Silsoe, on 27 September 1973.

†*Water conservation engineer, Essex River Authority.*

constructed away from the water source, frequently in the past insufficient attention has been given to the design of those works to ensure effective relationships between water available, the overall annual quantity of water needed, storage volume and abstraction capacity. As a result in a dry winter some reservoirs may not fill due to limitations in intake capacity during the less frequent high flow periods eg if there were only 30 days in a winter period on which flows were sufficiently high to enable abstraction to take place, with an intake capacity of 200 m^3 (262 yd^3)/d it would be impossible to fill an 8000 m^3 (10 480 yd^3) reservoir but with an improved intake arrangement the reservoir could be filled.

River authorities can give some guidance in this matter particularly where there are gauging records over a sufficiently long period. Flow duration curves can be produced which will enable a reasonable assessment to be made of the quantities of water likely to be available for abstraction in various years, ranging from dry to wet, for given intake pump capacities after taking due account of any downstream priority flows which have to be maintained. A typical set of curves (fig 3) is shown in Appendix 1, together with calculations illustrating their use. While these curves are for a 12-month period smaller curves can, of course, be produced to cover other periods eg summer or winter six months. Proper application of these curves should enable the economic relationships between intake capacity, storage volume and cost to be critically examined and allow a rational choice to be made.

Where gauging records are of inadequate length to enable meaningful duration curves to be produced, curves for a neighbouring catchment can be utilised provided there is reasonable flow correlation. However, it should be mentioned that some caution is needed when interpreting results as varying hydrogeological factors can produce substantial variations in run-off. Local knowledge of these matters must be taken into account as must any changes over the years in abstractions and effluent returns. It is desirable to carry out short period gauging to allow some correlation with existing River Authority records. River authorities are charged with the duty of setting up and managing a network of gauging stations and collecting hydrogeological data; this knowledge in conjunction with the compilation and use of sets of flow duration curves means they are well placed to give sound advice to anyone preparing an irrigation scheme provided, of course, that they are consulted at an early stage in the design.

Types of surface storage

Basically there are two types of storage reservoir, namely, on-stream and off-stream. Each has certain advantages over the other and while off-stream reservoirs are probably least complicated, provided control works are properly designed and constructed the best type of reservoir for a particular site is usually governed by site characteristics.

(a) On-stream

With the on-stream reservoirs, the dam is built across the stream and all flows enter the reservoir; consequently overflow works must be adequate to cope with major flood discharges from the full upstream catchment. Also, when water is abstracted in the summer and the water level is drawn down below the overflow level, unless suitable discharge systems are provided, water would cease to flow downstream. For most new reservoirs some arrangement (such as a valved pipe outlet) will be necessary to provide the amounts of water required to protect downstream interests. Due to the fact that all higher flows pass through these reservoirs they are more likely to collect the required quantity of water than off-stream reservoirs where the intake capacity is a limiting factor.

(b) Off-stream

The off-stream reservoirs can be located at any convenient site where geological conditions and ground contours are suitable. In some cases they can be filled by diverting water from the stream to gravitate into storage but in most cases pumping is needed. Irrespective of the method of filling, a suitably designed intake system is required to pass priority flows downstream. Such systems are more straightforward and generally cheaper than the arrangements necessary for on-stream reservoirs. When the reservoir is full all flows by-pass it and expensive overflow works are unnecessary. Abstractions into these reservoirs, unlike on-stream ones, can be licensed so that abstractions are only allowed during winter months, giving a financial advantage from lower abstraction charges.

Priority flows

River authorities are not allowed to grant a licence which would derogate from existing abstractors' rights and therefore most new licences are likely to include a condition whereby abstractions can only be made subject to the passing of a priority flow (sometimes called a minimum acceptable flow) downstream. This flow will be the minimum necessary to protect all legitimate downstream interests. Priority flows progressively increase as the utilisation of a catchment's resources increase. Furthermore, where there are major public water supply and/or industrial abstractions on the lower reaches of a river, priority flows can reach such a level that in drier years insufficient water remains available to meet any new requirements. Almost 90% of the Essex River Authority's inland catchments contribute to public water supply with intakes at tidal limits; in consequence priority flows have to be set to a high level to protect these abstractions. The values largely range up to the equivalent of 3.3 l/s per km^2 (0.41 gal/s per $mile^2$). Flows above this level occur typically on about 80 days in an average year. However, in a driest year in ten the number of days when water is available may reduce to little more than 20, and during a drought of similar severity to 1933/34 or the past year abstraction could be virtually precluded altogether.

In 1971 the Essex River Authority completed the Ely Ouse – Essex Scheme, which enables water to be abstracted from a neighbouring catchment to the north and discharges into the headwaters of two rivers with facilities provided for future extensions to discharge into three more (fig 1). Any irrigator on the carrier rivers can, of course, receive some direct benefit from this scheme. Furthermore, where there is more water available for transfer than the amount required to meet all licensed abstractions on the carrier rivers, the level of priority flows required to be passed by licensees on tributaries can be temporarily lowered to help fill their reservoirs. Any subsequent short fall in the main river being made up by importation of additional water. During the very dry winter we have just had the initiation of such a policy, with the full co-operation of all concerned, not least water undertakings, has resulted in many reservoirs which would have been almost empty at the commencement of the irrigation season being full or substantially so. It is envisaged that as river regulation and the transportation of raw water supplies in rivers rather than in pipes becomes more widespread, further opportunities will be presented for the development of similar arrangements which will enable the fullest use to be made of all available resources to the benefit of all water users.

Groundwater

Groundwater for present purposes can be conveniently divided into that contained in aquifers in solid geological strata and that contained in superficial deposits. By and large the former comprise the major aquifers of this country and consequently for the want of better terms they are classified as major and minor aquifers respectively.

Major aquifers

These include the chalk, limestone and bunter sandstone and can extend to a great depth. In general, provided boreholes are properly constructed adequate yields should be available to match outputs from irrigation sets. However, due to the very nature of these aquifers they are heavily reliant on fissuring to provide good transmissibility and in many areas a substantial depth of borehole may be required to give an adequate yield. Fissures are usually more prevalent in valley bottoms and therefore borehole yields tend to decrease with distance away from a river.

Means of increasing borehole yields include surging, acidising and the use of explosives, but these techniques should be carried out only by companies experienced in these matters. Bores should be lined throughout the superficial deposits and tubes grouted in to prevent the ingress of sand and surface pollutants.

These aquifers provide the main source of groundwater for public supply purposes and also provide large quantities of water for industry; as a result, in many areas they are fully committed and sometimes over-committed. In such cases river authorities are unable to grant new abstraction licences for irrigation (or any other use).

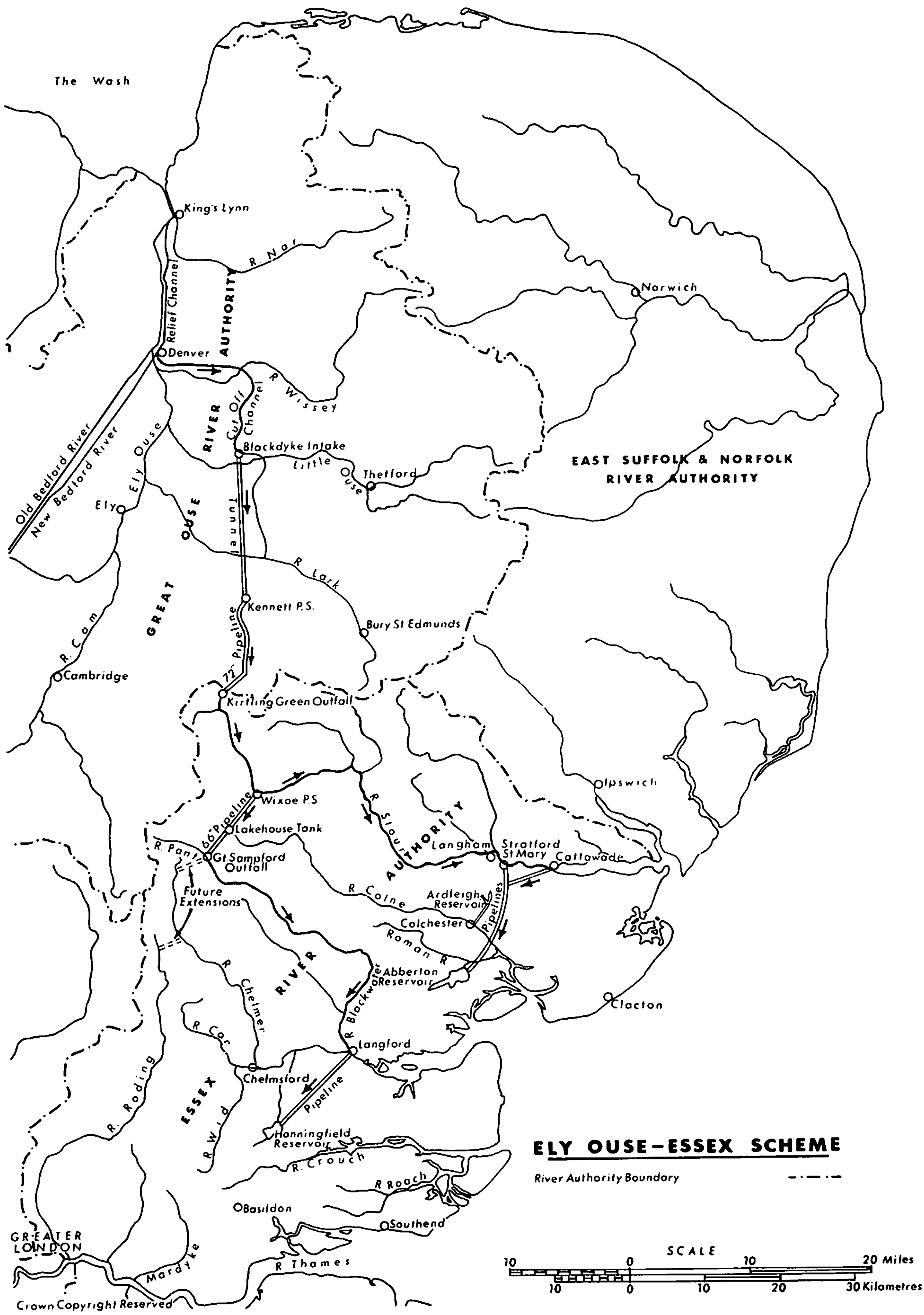

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Fig 1

Where new licences can be granted a properly constructed borehole perhaps 200 mm (8 in) in diameter can provide an extremely reliable source of supply as the very large volume of water contained in the aquifer smooths out the effects of short and medium term droughts.

Due to the frequent need to construct boreholes of much greater depth than those required to exploit superficial aquifers, construction costs may be substantially higher. Further, one must be prepared for occasional abortive expenditure which would result if the bore does not intercept a satisfactory fissure system. Development of the borehole may increase the output to an adequate level, but after spending additional money for this purpose it is still possible the yield may be insufficient to meet requirements.

Minor aquifers

These mainly comprise glacial sands and gravels and other superficial deposits. Regardless of their classification they are likely to provide the main sources of groundwater for new irrigation abstractions. Unlike the major aquifers they tend to be fragmented with extremely variable yields. In keeping with all groundwater aquifers their storage potential is a distinct asset but sometimes this may not be sufficient to overcome declining water levels during a prolonged drought.

Frequently insufficient scientific expertise has been brought to bear on the location and design of abstraction works and as a result full effective use has not been made of aquifer characteristics. The basic problem is one of designing and constructing a system which will not only provide water at a sufficiently high rate to match irrigation set needs but will also be able to sustain the yield throughout the full irrigation season, even in times of drought. All too frequently inadequate investigations are carried out to determine the extent of the aquifer and its properties, and the best place to abstract. Often a pumping test is continued for only a few hours and without the use of an observation bore, with the sole object of assessing the instantaneous yield of the well without regard to seasonal effects.

Bearing in mind the fact that groundwater schemes are normally much cheaper than reservoir schemes and do not require the flooding of land, expenditure on groundwater exploration can be money well spent.

To obtain maximum advantages from a locally available aquifer the best use must be made of the aquifers characteristics and the following points are relevant:

(Bearing in mind the variability of aquifers, figures quoted below must only be regarded as very approximate guides.)

(a) Examination of the base-flow of springs in the vicinity and seepage lines can provide a good appreciation of extent of aquifer and a well survey can give a good indication of groundwater contours and pattern of flow.

(b) The best location for the point of abstraction in relation to the area of land to be irrigated may not be the best from the viewpoint of getting the required yield. The abstraction point should be sited down gradient where an adequate area of aquifer can contribute to yield. The proximity of existing abstractions must also be borne in mind.

(c) Well capacity is roughly proportional to the permeability of the strata and also aquifer thickness but only increases slowly with diameter.

(d) The well diameter should be sufficient to obtain the required output eg a 1.2 m (4 ft) diameter well will discharge only about 20% more than one of 0.3 m (1 ft) diameter for the same drawdown of water level. In some cases an alternative type of collector system may be more economic than a well of very large diameter.

(e) To obtain maximum flow from a given water bearing formation the well should be constructed to the bottom of the aquifer. When this is done, in a non-artesian formation, a broad guide to the yield – drawdown relationship is that only 75% of the maximum discharge is obtained when the drawdown is equal to half the depth of water in the well before pumping commenced.

(f) A properly planned pumping test should be carried out over a period of at least three days with water levels measured in the pumped well and in a suitably located observation well perhaps 15 to 40 m (16–45 yd) away, before starting pumping, during the steady pumping and during recovery so that aquifer characteristics can be calculated.

(g) If one well cannot provide sufficient water a second well should be so located that the inter-action of their radii of influence is not too great eg two wells spaced at about one-quarter of their radii of influence will yield about 75% more than a single well. Test pumping data will provide guidance for the siting of a second well.

(h) Development of a well is necessary to obtain maximum capacity for a given drawdown. This can be done by surging using a surge block, alternatively, frequent starting and stopping of a pump, or possibly the dumping of dry ice into the water can be used (the rapid change to gas creates violent turbulence). The object of developing a well is to remove fine material from the formation in the immediate vicinity thereby allowing water to move more freely into the well.

(i) If the water bearing strata consists of well graded material then development as in (h) is probably all that is necessary to create a good natural filter having adequate hydraulic characteristics and long life. Otherwise a gravel pack filter supported by a perforated well screen would be beneficial. To keep velocities and therefore head loss to an acceptable level, well screen waterway openings should be about 20% of the screen area – and slot size should retain 90–95% of the gravel filter. For effective performance a gravel filter should be chosen so that its 50% size is not more than four to six times the 50% size of the sand and/or gravel forming the aquifer.

(j) Where the transmissivity of an aquifer is poor it is sometimes difficult if not impossible to design an economic collector system which can provide an instantaneous yield to match irrigation requirements and consequently some balancing storage may be necessary. A convenient means of doing this is to construct a seepage reservoir to act as a pump sump; this, as well as providing the necessary balancing storage has the added advantage of providing a large area of interface between the strata and sump thus increasing the instantaneous flow. Incidentally, the excavated materials may have a commercial value which more than pay for construction costs.

(k) A system of screened well points (small diameter pipes jetted or driven into the strata) can provide a good spread of abstraction area and in suitable locations can provide an economic abstraction system. Furthermore, the equipment may be hired then if successful bought from the hirer.

(l) Where the abstraction pump relies on suction lift to get water to the surface, care must be exercised to ensure that in severe droughts a combination of pump drawdown and a natural lowering of the water table does not result in excessive suction with an unacceptable fall off in pump output – at the very time when water is most needed.

(m) For maximum efficiency do not buy the pump before carrying out a pumping test. Analysis of the test results will then enable the pump characteristics to be chosen to match the output characteristics.

Non-availability of water

It must be emphasised that the granting of a licence to abstract a certain volume of water does not guarantee that the full quantity will be available when wanted; failure to recognise this can lead to conflict. In the past the Ministry of Agriculture usually required to be assured of the availability of the theoretically correct amount of water needed to meet a scheme's full requirements, before they were prepared to give grant-aid. On a number of occasions an applicant has been informed that the imposition of a high minimum acceptable flow (priority flow to maintain existing rights) would result in the full water requirement being available perhaps only six or seven years or of ten. However, the full requirement was still requested 'because that was the quantity needed on a licence to obtain a grant'. It is understood this situation no longer applies but it is submitted that all concerned with the planning of irrigation schemes, including consultants and individual farmers must beware of generating 'paper' water and ensure that calculations to ascertain a scheme's viability are based on quantities of water which are likely to be available rather than quantities printed on licence documents. Only by so doing can the true economics of a scheme be assessed, and bearing in mind the fact that the years when insufficient water is available will coincide with drought situations when there will be the largest return from irrigation, a substantial short fall in say three years in ten will have a big impact on a scheme's viability.

Return of water

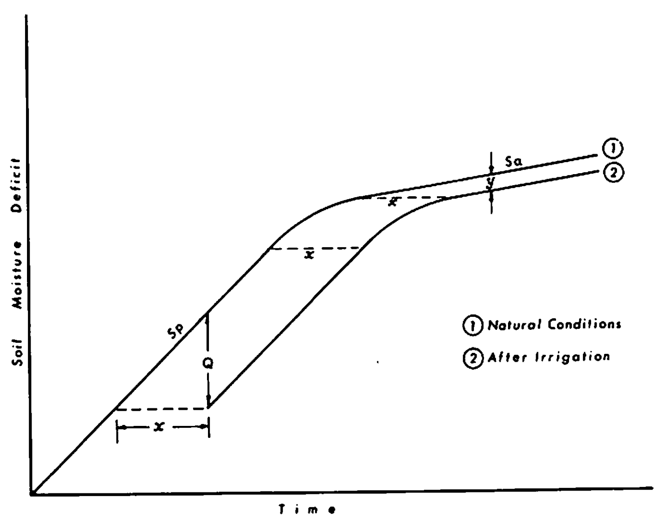
River authority charging schemes take account *inter alia* of the quantity and quality of water returned. On the question of quantity of water returned to resources, for many years the view has largely been taken that there is little or no return from irrigation water when it has been properly applied. This view is considered to be too extreme and the Essex River Authority Charging Scheme reflects this by allowing for a 15% return to the assessment of charge rate for irrigation abstractions.

When the new regional water authorities come to prepare new charging schemes no doubt the question of percentage return will again come to the fore, and therefore the time may be opportune for a discussion on this issue. Appendix 2 gives a very much shortened version of a series of calculations carried out for the River Stour (Essex and Suffolk) catchment to ascertain the quantity of water returned to resources which might result from different patterns of irrigation in years of varying drought severity. Fig 4 gives a graphical representation of the results. From this it is clearly seen that there is a return of irrigation water to resources, albeit variable both in quantity and time. This return takes the form of a reduced soil moisture deficit at the end of the summer, which allows the seasonal winter increase in flows to begin earlier than it otherwise would have.

In wet years, and/or for crops with high root constants, when evaporation is unrestricted, soil moisture deficit would be reduced by the full amount of irrigation applied (in such a case irrigation would have served little purpose anyway). However, in drier years and/or for crops with lower root constants, evaporation under national conditions is restricted and where irrigation has been applied, the plants make use of it, thereby allowing the soil moisture deficit in the irrigated area the opportunity to partly catch up. Provided the object of irrigation is attained, ie it is ensured that transpiration can take place without restriction, the percentage return of water is only affected by the total seasonal quantity of water applied and not the amount and frequency of individual applications.

If the evaporation model used by the Meteorological Office[5] is correct then the deficit after irrigation can never catch up with what it would have been without the additional water; irrigation effectively delays the growth of a deficit for a certain period of time, say 'x' weeks. Deficit-time curves for irrigated and non-irrigated areas shown in fig 2 then rise parallel but 'x' weeks apart and while both curves remain in the root constant zone the vertical

Growth of Soil Moisture Deficit (In absence of rainfall)



Sp – Rate of Potential Evaporation
Sa – Rate of Actual Evaporation when Deficit $>$ Root Constant
Q – Amount of Irrigation Applied
y – Net Gain to Resources

$$Sp = \frac{Q}{x} \quad \therefore x = \frac{Q}{Sp}$$
$$Sa = \frac{y}{x} \quad \therefore y = x \times Sa$$
$$\therefore y = Q \times \frac{Sa}{Sp}$$

Fig 2

distance between them (ie the amount of irrigation water not yet used by the crop) is equal to the amount of irrigation water applied. When the rate of increase of deficit on the non-irrigated area slows down due to lack of moisture the irrigation crop draws on its reserve of irrigation water and the vertical gap narrows until the deficit on the irrigated area reaches the same break point and thereafter the two graphs again run parallel. The geometry of the figure shows that:

The net gain to resources =

$$\text{irrigation applied} \times \frac{\text{actual rate in increase in } SMD}{\text{potential rate of increase in } SMD}$$

which, using the Meteorological Office model of actual evaporation, implies a minimum return to resources of some 8.5%. This is the opposite extreme to the 100% case described above but reality will usually lie in between.

While the above hypothesis would appear to hold good for medium and large root constants and for smaller root constants in wet seasons, there would appear to be a 'grey' area for those cases where the root constant is small and where water is applied in drier than average seasons. The fundamental question to be answered is, what happens, from the evaporation viewpoint, as soil tension approaches and reaches the maximum which plants can generate to lift water from the lower horizons. Until more knowledge is gained on this subject there is little point in pursuing the evaporation return question much further in these particular cases.

On the general question of time of application of water and subsequent return; crop irrigation when continued until near the end of season leaves limited time for the natural evaporation process to catch up non-irrigated deficits and consequently substantial water returns will arise (on average evaporation is less than rainfall in September with perhaps only a 30 mm (1.2 in) difference in August). Bearing this position in mind it would appear good economics where irrigation is planned to continue late in the season, to work to a plan which allows for a progressive increase in *SMD* as the end of the irrigation period approaches.

Costs

During the first two or three years following setting up of the new regional water authorities one cannot foresee any major changes being made in the principles on which charges are based. What happens after that is difficult to predict, but one outcome is likely to be a more general equalisation of charges, particularly in those regions where an amalgamation of river authorities takes place. This would mean that the very low charges in some areas where construction of conservation works has not yet been necessary are likely to rise.

River authority 1973/74 summer abstraction charges for irrigation at present range from about 0.8p per m^3 to less than 0.1p per m^3 with winter rates in general ranging from half to one-tenth of the summer values.

Progressively, a general levelling up of charges is likely with summer and winter rates perhaps of the order of 1p and 0.2p/m^3 respectively. The seasonal difference reflects the availability and hence value of water in the two periods and will, of course, vary between regions according to hydrological factors. Abstractions from underground strata are frequently charged at a rate either equal to the winter rate or the mean of summer and winter values.

As surface sources become more committed so the use of storage reservoirs in conjunction with winter abstraction must increase. Any attempt to assess the impact of water charges on irrigation economics is fraught with difficulty due to the large number of variables involved, not least hydrological, construction and pumping costs, and irrigation plans. Nevertheless, such an exercise is of value in that it illustrates the approximate relationships involved:

Assume a scheme is based on irrigating 16.2 ha (40 acres) with 100 mm (4 in) of water. Three alternative means of obtaining the water are considered:

(a) A direct summer abstraction from a surface source.
(b) The construction of a reservoir in conjunction with a winter abstraction from a surface source.
(c) An abstraction from a gravel source using a well system.

Abstraction charges are assumed to be:
(a) £10.00 per $10^3 m^3$ ie £1.00/100 m^3
(b) £2.00 per $10^3 m^3$ ie £0.20/100 m^3
(c) £6.00 per $10^3 m^3$ ie £0.60/100 m^3
Note: 100 m^3 = approx. 1 acre inch and for convenience this metric unit is used throughout the calculations.

If the average water usage is 75% of licensed quantity and a 50:50 two-part tariff (Section 63 Agreement) is in operation, charges per 100 m^3 licensed will be decreased by the factor:

$$\frac{50 + 50 \times \frac{75}{100}}{100} = 0.875$$

then charges per 100 m^3 applied will be increased by the factor:

$$0.875 \times \frac{100}{75} = 1.17$$

Thus charges per 100 m^3 applied becomes:

(a) £1.17
(b) £0.23
(c) £0.70

For (b) 100 m (4 in) of water on 16.2 ha (40 acres) will require 16 400 m^3 (21 500 yd^3) storage.

	£
Capital cost of reservoir at say £200 per 10^{3}m^3	3280
Capital cost of abstraction pump and pumphouse etc	600
Irrigation pump, underground mains and fixed installation (£222/ha [£90/acre])	3600
Total for source works and fixed installations	7480
Total for source works and fixed installations after deducting 20% grant	5984
Capital cost of sprinklers and overground distributing system (say £136/ha [£55/acre])	2200
Capital cost of scheme to farmer	£8184

Assuming repayment is over 15 years @ 10% interest
Annual payments = 81.84 X £13.15 = £1076
Average number of 100 m^3 applied each year = 40 X 0.75 X 4 = 120

Capital cost per 100 m^3 applied = $\frac{£1076}{120}$ = £8.97

Pumping costs, repairs, maintenance, transport etc =	£1.20
Labour =	£1.20
	£11.37
	/100 m^3

by £3880 (ie £3104 to the farmer) giving a cost per 100 m^3 applied of £8.97

For direct summer abstraction (a) capital cost would be reduced by £3880 (ie £3104 to the farmer) giving a cost per 100 m^3 applied of £8.97 X $\frac{5080}{8184}$ + £2.40 = £7.97.

For an abstraction from the gravel source (c) capital cost of source works may be reduced to £1000 (ie £800 to farmer) giving a total capital cost to farmer of £800 + £3600 X 0.8 + £2200 = £5880

$\therefore$ cost per 100 m^3 applied = 8.97 X $\frac{5880}{8184}$ + £2.40 = £8.84.

Each additional £1000 capital spent on grant-aided work (£800 to the farmer) would increase farm costs per 100 m^3 by £.088.

Because of likely variations in costs these figures must not be taken too literally, but they do indicate that as abstraction charges rise they will progressively erode the cost differentials between direct summer abstractors and those needing to construct works to obtain water. Furthermore, the figures give an indication of the percentage costs directly attributable to charges ranging from about two per cent for a reservoir scheme to nearly 13% for direct abstractions.

These operating costs should be viewed in relation to the increased response of various crops to irrigation with perhaps present average increased margins per 100 m^3 or irrigation being approximately:

Potatoes early	– £35
main crop	– £20
Sugar beet	– £8
Grassland	– £6
Top fruit	– £20
Vegetables	– £35

Total costs – £ per 100 m^3 applied

	(a) *Direct summer abstraction*	(b) *Reservoir with winter abstraction*	(c) *Abstraction from gravel strata*
Operating costs	7.97	11.37	8.84
Water charges	1.17	0.23	0.70
Total	9.14	11.60	9.54

On this basis a new scheme for the sole irrigation of sugar beet, grassland and low value crops would not be economic. However, for high value crops irrigation would still appear to be good value, and one questions why irrigation is not increasing at a faster rate than it is?

References

1 MAFF Technical Bulletin No. 4 'The calculation of irrigation need'
2 MAFF Technical Bulletin No. 16 'Potential transpiration'
3 MAFF Bulletin No. 138 'Irrigation'
4 MAFF Bulletin No. 202 'Water for irrigation'
5 Met. Office Hydrological Memorandum No. 38 by J. Grindley.

Appendix 1

Flow duration curves

Flow duration curves provide a plot of average daily flow against the number of days on which each flow is equalled or exceeded. Fig 3 gives curves relating to the River Stour (Essex and Suffolk), covers the 12 months April to March and are based on 34 years gauging. The area under each curve is a measure of the volume of water available for the particular probability of dryness with one square (of the graph) equal to 160 m^3 (210 yd^3) (40 X 4) for each km^2 (0.39 mile^2) of catchment contributing to the flow.

Example in use of curves

Assume:

(a) A farmer's irrigation plan requires a reservoir with a capacity of 10 000 m^3 (13 100 yd^3).

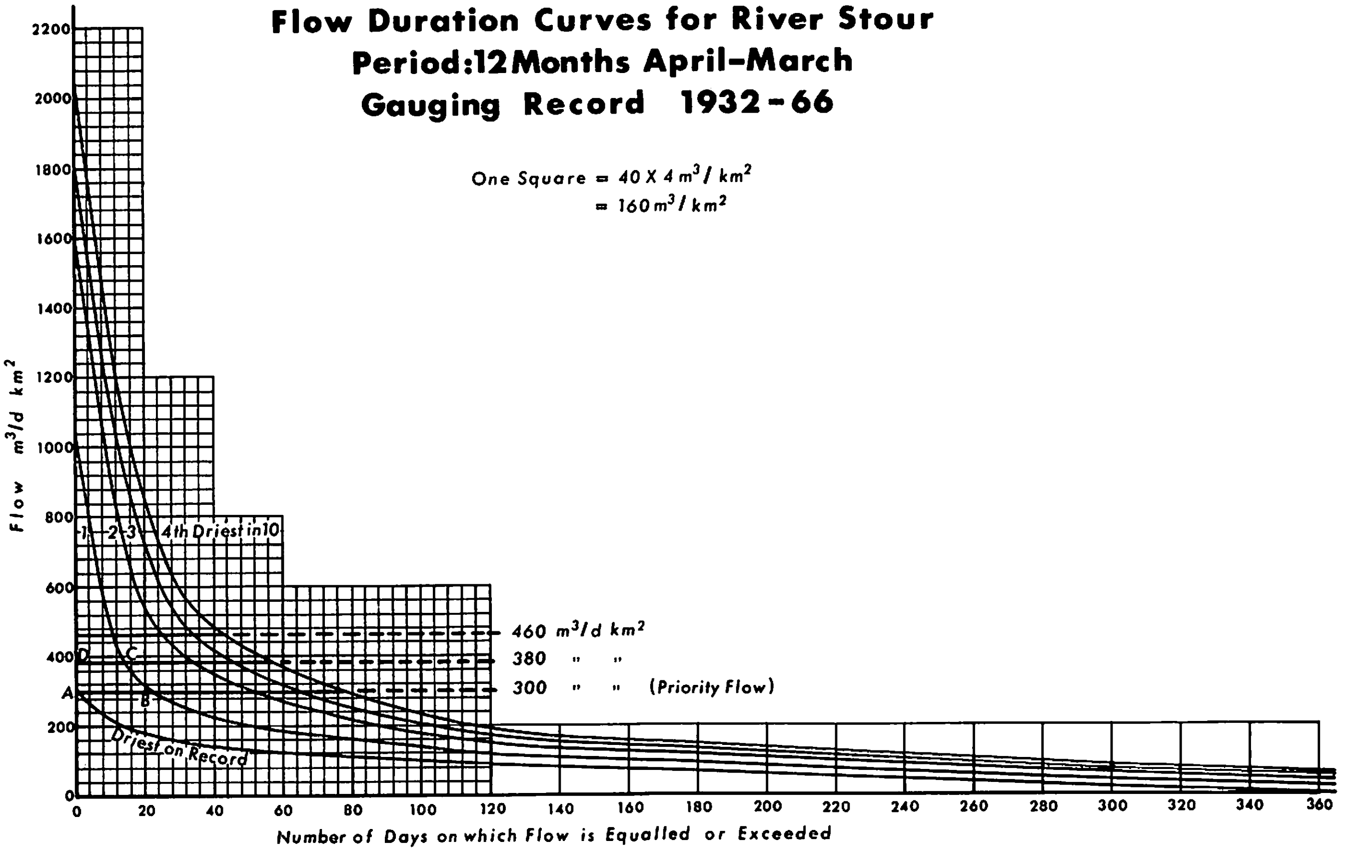


Fig 3

(b) Catchment contributing to the intake = 2.5 km² (0.97 miles²). (0.97 miles²).

(c) Priority flow required by River authority to be passed downstream before abstraction can take place = 750 m³ (983 yd³)/d, ie 300 m³ (393 yd³)/d km² (0.39 mile²).

(d) Choice of intake pump capacity available – 200 m³ (262 yd³)/d (equivalent to 80 m³ [105 yd³]/d km³ [1308 yd³]), or 400 m³ [524 yd³]/d) (equivalent to 160 m³ [210 yd³]/d km² [0.39 mile³]).

Area *A B C D* represents the volume of water in a driest year in ten available for abstraction with the 200 m³ (262 yd³/d pump at flows above the priority flow. This area totals 8.3 squares and therefore the volume of water available in the year = 8.3 X 160 X 2.5 = 3320 m³ (4350 yd³).

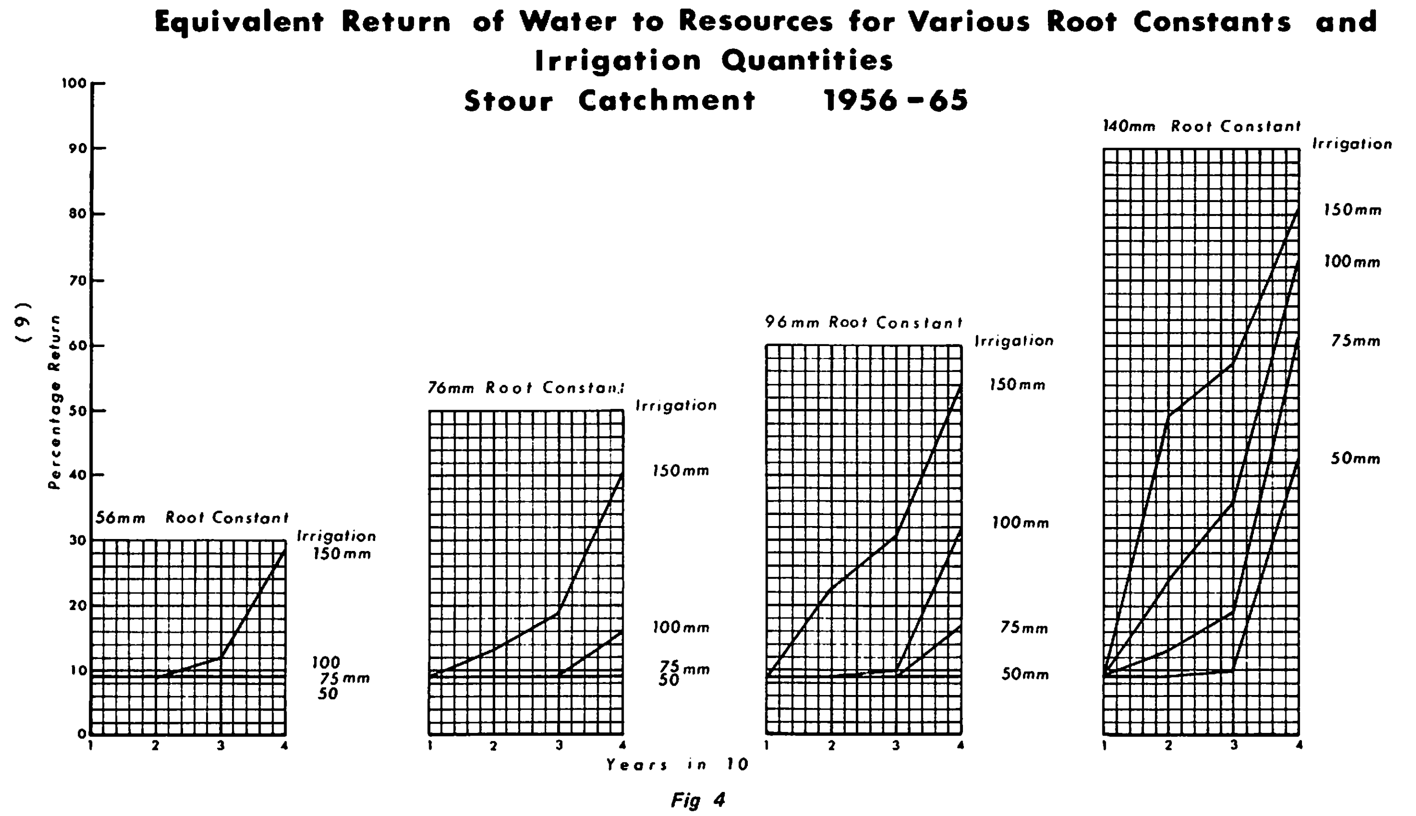


Fig 4

In a similar manner quantities can be computed for other years with both pump sizes giving the following:

Volume of water available in m³

	Driest year in ten	*Second driest*	*Third driest*	*Fourth driest*
200 m^3/d pump	3320	8200	10600	13000
400 m^3/d pump	5600	13800	18200	23200

Thus with the smaller pump the farmer will be able to completely fill his reservoir seven years in ten, but this can be increased to nine years in ten if the larger pump is used.

Bearing in mind the fact that in this latter case in the driest year only a little over half the required water would be available, consideration may be given to whether it was economic to increase the pump size still further and, of course, appropriate calculations can be made to ascertain whether it would be worthwhile.

One matter which should be taken into account is the fact that the previous summer may have been wet and therefore the fill-up period may start with some water already in store.

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APPENDIX 2

River Stour Catchment
Equivalent return from irrigation in 1964
(Third driest in period 1956–65)
(all values in mm)

		Apr	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*			
(1)	R	61	30	81	25	25	10	31			
(2)	PE	49	91	80	95	87	61	15			
(3)	PE – R	–	61	–1	70	62	51	–16			
(4)	Cum. PE – R	–	61	60	130	192	243	227			
(5)	Act. SMD 56 mm RC		61	60	93	98	102				
(6)	76 mm RC		61	60	111	116	121				
(7)	96 mm RC		61	60	124	135	139				
(8)	140 mm RC		61	60	130	174	179				
									Alternative total irrigation application		
	Irrigation application plan – apply 25 mm at 25 mm deficit										
(9)	56 mm RC 150 mm irrig.		50		75	25			100	75	50
(10)	Cum. def.		11	10	5	42	93		143	168	193
(11)	Act. SMD		11	10	5	42	84		93	96	98
(12)	% return						$\frac{18}{150} = 12$		$\frac{9}{100} = 9$	$\frac{6}{75} = 8$	$\frac{4}{50} = 8$
	Irrigation application plan – apply 25 mm at 38 mm deficit										
(13)	76 mm RC 150 mm irrig.		25		75	50					
(14)	Cum. def.		26	25	30	42	93		143	168	193
(15)	Act. SMD		26	25	30	42	93		113	114	116
(16)	% return						$\frac{28}{150} = 19$		$\frac{8}{100} = 8$	$\frac{7}{75} = 9$	$\frac{5}{50} = 10$
	Irrigation application plan – apply 25 mm at 38 mm deficit										
(17)	96 mm RC 150 mm irrig.		25		75	50					
(18)	Cum. def.		26	25	30	42	93		143	168	193
(19)	Act. SMD		26	25	30	42	93		129	133	135
(20)	% return						$\frac{46}{150} = 31$		$\frac{10}{100} = 10$	$\frac{6}{75} = 8$	$\frac{4}{50} = 8$
	Irrigation application plan – apply 25 mm at 50 mm deficit										
(21)	140 mm RC 150 mm irrig.		25		75	50					
(22)	Cum. def.		26	25	30	42	93		143	168	193
(23)	Act. SMD		26	25	30	42	93		143	165	174
(24)	% return						$\frac{86}{150} = 57$		$\frac{36}{100} = 36$	$\frac{14}{75} = 19$	$\frac{5}{50} = 10$

Notes: R = rainfall, PE = potential evaporation, SMD = soil moisture deficit, RC = root constant.
Lines (1) and (2) are actual recorded figures. Lines (5)–(8) are derived from line (4) using tables 3, 4, 5 and 6 in reference (5).
Line (11) is derived from line (10) using table 3 in reference (5).

$$\text{Line (12)} = \frac{\text{line (5)} - \text{line (11)}}{\text{total irrig. applied}}$$

If lines (21)–(23) had been based on an irrigation plan of applying 37.5 mm at 75 mm deficit it would affect the times when irrigation was applied but would not alter line (24) ie as the object is to ensure transpiration can take place without restriction if this object is attained the percentage return is only affected by the total seasonal quantity of water applied.
The years 1956–65 for the Stour gave a reasonable approximation to the standard rainfall values for a ten-year period given in numerous *MAFF* publications. These values can, of course, be used for calculation of equivalent returns of irrigation water for any area using average potential transpiration values.
The full results for first, second, third and fourth driest years in ten are shown graphically in fig 4.

The Evolution and Evaluation of Irrigation in Britain*

by W. B. J. Withers BSc(Tech) MICE†

Summary

THIS paper is a study of the relationship between research and field practice of irrigation in Britain. Various aspects of the background to irrigation are reviewed – its economic functions, trends in use, and its early history. The evaluation of irrigation is considered as applied to three distinct features of its practice – agronomy, economics, and the operation of field systems. A discussion on current trends in research is followed by comment on possible future developments.

1. Introduction and background

Irrigation is a word with a simple dictionary definition but a wealth of meaning, emotional as well as rational, which is derived from the experience of the individual. Different people working within the broad field of irrigation do not necessarily see its objectives in the same light. The farmer tends to be primarily concerned with its economic function in increasing profits or its management function in improving control over plant growth. The research worker tends to be most interested in its physiological effects on the plant, or in a related field such as soil physics or irrigation hydraulics. It is the purpose of this paper to examine the relationship between research and the practice of irrigation in Britain.

1.1 Irrigation economics

Irrigation in Britain is supplemental and as such has a relatively clear-cut economic function compared with that of irrigation in an arid climate, where the issue is complicated by political and social implications. Since rainfall in Britain is normally sufficient to sustain plant growth, irrigation is an economic exercise – it represents a non-essential investment which is justified by the benefits it is expected to produce.

The most obvious function of irrigation is to increase the yield of saleable produce and so increase farm income. In many cases short-term economic analysis is sufficient to show the merits of such irrigation. When applied to vegetables or early potatoes in Eastern England, for example, it is known that natural rainfall is insufficient to meet full crop water requirements in eight or nine years out of ten. Costs of irrigation water and the means of applying it are compared with expected increases in yield and the consequent extra income.

However, crop by crop study of irrigation as it is practised in Britain reveals that its primary function in many cases is not to give a direct increase in saleable produce but rather to give improved control over plant growth. This is well illustrated by the irrigation of grass for a dairy herd. The cash value of the extra grass grown is low. Irrigation of vegetables gives from five to 20 times the cash return per unit volume of water. (Irrigation in Britain, 1962.) The value lies in the removal of major fluctuations in yield from year to year and hence in the provision of much improved control over the stocking rate. The farmer is saved from the dilemma of choosing between a high stocking rate which results in loss of milk yield in a dry year, and a low stocking rate which does not make full use of available grass in a wet year.

There are other crops for which irrigation stabilises yield or performs some similar function to give better control over farming, marketing, or food processing – it can be used to induce uniform maturation of the crop or to make better use of fertilisers. But these are all aspects of irrigation used as a tool for improved farm management, with an indirect effect on profitability as compared with the direct effect considered previously.

1.2 Irrigation statistics

1.2.1 Trends

Statistics are available from periodic *MAFF* special irrigation surveys since 1963. These indicate that the rapid increase in sprinkler irrigation which marked the late fifties and early sixties declined in the late sixties and gave way to an overall decrease between 1967 and 1972. Among the major irrigated crops the most notable effects were static situations in first early potatoes, soft fruit, and vegetables, a decline in second early and maincrop potatoes, a fluctuating situation in sugar beet, and a large decline in grassland (fig 1).

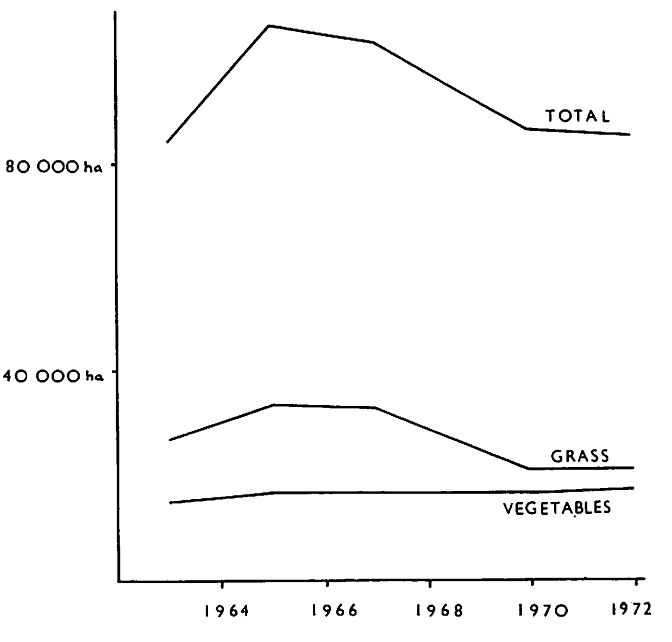

Fig 1 Area of crops usually irrigated in a dry season (from MAFF Special Irrigation Surveys).

Taking the areas of land under the various crops for which irrigation would be viable as those given in the Natural Resources (Technical) Committee Report (1962), the percentages of these areas actually irrigated in a dry year currently ranges between 15% for early and maincrop potatoes, and 27% for vegetables. This suggests that there are still large areas of land under all the major irrigated crops for which irrigation would be highly profitable. Penman in 1963 went as far as to predict a total irrigated area of 200 000 ha (494 200 acres) by 1980, rather more than twice the current figure. The trend of recent years cannot be satisfactorily explained as a saturation effect. The question is whether there are problems in the practice of irrigation which research organisations should be tackling, or whether the decline of irrigation has been just

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one manifestation of the effects of economic forces on agriculture as a whole.

If investment in agricultural equipment in general were static during the period 1967–72, the stagnation in irrigation development would be understandable as reflecting a general trend. The figures for gross fixed capital formation in agriculture, adjusted for inflation, indicate that this may have been the case since 1968 but are far from conclusive. Possible then here was part of the answer – shortage of funds rather than disenchantment with irrigation.

During this period, control over water use increased. Charges were imposed and licenses for abstraction became a requirement. Even so, the highest charges by river authorities, Essex and the Great Ouse, are a small proportion of the extra profits, which can be obtained by irrigation, and licences can be obtained in most cases provided that the water user is prepared to instal a reservoir. It is notable that the irrigation of vegetables increased and that much of this irrigation is with mains water supply at a price at least 2.5 times that of the most costly river abstraction charges.

The number of people employed in agriculture continued to decline steadily. To many farmers labour shortage was and continues to be a problem and low labour irrigation systems are a necessity. These increase the initial outlay required and must tend to act as a deterrent to irrigation.

There are many other factors which doubtless have had some influence on the apparent decline of irrigation over the period 1967–72. (There have been no years of severe, nationwide drought. There was some ambiguity in the form of the questions on the survey.) However, it seems that the reasons have been mainly unrelated to the techniques of irrigation and crop responses.

1.2.2 Risk taking

It has been found that attitudes to risk taking vary considerably between different groups of farmers, vegetable growers being among those most prepared to take a risk in the hope of obtaining an increased profit and dairy farmers being the least willing gamblers.

It is interesting to note that irrigation of vegetables is characteristically speculative and that it has been constant or continued to increase in recent years, whereas the irrigation of grassland has the function of insurance and has declined most severely.

2. Notes on the early history of irrigation in Britain

Irrigation has been practised in Britain for several centuries. A report written in 1846 claims that it was first introduced at Brabraham in Cambridgeshire by a man called Pallavicino. He was collector of Peter's Pence in England at the time of Mary Tudor's death. Finding he had a considerable amount of cash in hand on that occasion, he appropriated it for his own use, turned Protestant, bought the estate at Brabraham, procured a grant from the Crown for the river passing through, and introduced irrigation.

It was during the first half of the nineteenth century that irrigation enjoyed widespread popularity. The *Journal of the Royal Agricultural Society of England* for the period 1845–63 is rich in accounts of its use. The greatest success was found in the irrigation of grassland, both in valley bottoms and on hill slopes. Reclamation procedures for moorland and boggy hillsides are described in detail. Field channel systems, agronomy under irrigation, and the economics of individual cases are discussed at length and with evident enthusiasm. Due to the lack of scientific understanding of water quality at the time, there is speculation on the effects of solids in suspension and solution. The use of farmyard waste and road scrapings to enrich irrigation water is advocated with evangelical fervour.

The irrigation systems used in that period were intended primarily for watering the ground during winter and early spring, a procedure which has been found to bring on an early growth of grass. Watering during the summer was used for hay production but not for grazing because it was found to cause 'the rot' in sheep.

John Roals, in 1845, described the reclamation of a moory hillside in Somerset. Deep peat was drained by trenches of 2 m (2.19 yd) depth. Broken stone was placed in the trench bottom, covered by puddle clay to within 150 mm (6 in) of the ground surface, and topped off with topsoil. The drained land could then be irrigated and this was accomplished by tapping springs and running them into a system of shallow (75 mm [3 in]) surface channels.

P. Pusey, a leading exponent of irrigation, commented, 'The two pages of this (John Roal's) report contain a talisman by which a mantle of luxuriant verdure might be spread over the mountain moors of Wales and Scotland, Kerry and Connemara'. Then followed condemnation of those owners of 'needless deserts' who failed to take action.

Also in 1845, Lord Braybrooke wrote that Italian ryegrass was successful under irrigation on his land. He noted that spring temperatures had a strong influence on subsequent grass growth.

In 1851, Robert Smith gave an account of hillside catch-meadows on Exmoor. He put forward many points which deserve noting today:

(i) Reclamation should be carried out in an orderly, phased manner '. . . each succeeding operation steadily and progressively directed to form its part of the integrated whole'.
(ii) Field irrigation channels should be directed through ponds into which livestock sheds discharge their effluent. In the off season for irrigation dung should be composted and stored for addition to irrigation water the next season.
(iii) Stagnation of water on the ground surface should not be allowed. Spoil from ditch excavation should be used to fill in hollows.
(iv) Grassland should be sheltered by plantations of trees.
(v) Every care should be taken lest 'fine particles of soil, manure, lime, or ash be washed to the bottom of the hill by collecting currents – never, alas! to be regained'.
(vi) Reservoirs should be used to make use of small streams or winter rains.
(vii) There should be generous agreements between landlord and tenant farmer to encourage hillside improvement.

The field system used by Roals was a series of channels along the contours of 40 m (44 yd) spacing which could be made to overflow on their downslope banks. Between these channels were parallel shallow ditches to collect and redistribute the flow.

In 1852, John Bickford described a new system of irrigation. A main channel, or 'carriage gutter', was built along the highest side of the field. This supplied a grid of small ditches, or 'watering gutters', 100 mm (4 in) wide and 100 mm (4 in) deep, slightly inclined to the contours of 10 m (11 yd) spacing and perpendicular to the contours at 10 m (11 yd) to 15 m (16.4 yd) spacing (fig 2). Sods cut in the formation of the small ditches were used as stops to control flow. Basically, the water flooded down the field from one contour channel to the next. Extra control of the water to the lower levels was exercised by use of the downslope channels. These various channels were recut every year by a purpose-built plough. It was claimed that this system of irrigation caused no impedance to mowing or carting hay, was no danger to livestock, and induced good surface drainage. The older system it superseded used much larger and more widely spaced contour channels. Bickford argued that his method was 'easy and therefore pleasant to do and therefore sure to be done'.

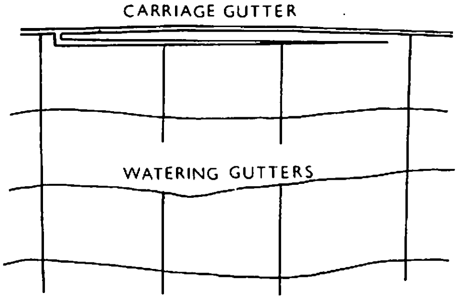

Fig 2 Bickford's improved system of irrigation (1852)

P. Pusey noted that the reasons for the success of irrigation were not certain and that the phenomenon was complex – a remark which has not dated.

Also in 1852 a report on agriculture in Cumberland referred to the use of town sewage from Wigton by the Rev Mr Matthews which was successful on his grassland. There was severe criticism of towns, Penrith being an example, which 'send the fatness of their streets and sewers into the nearest stream, with only feeble attempts to arrest their fertilising properties'. No-one seemed to be worried about pollution of the stream!

In 1863 there were further reports on the use of town sewage for irrigation, one referring to Watford, the other to Rugby. It was mainly applied to permanent pasture or Italian ryegrass.

In the latter part of the nineteenth century irrigation received little mention. Presumably it was a victim, like drainage, of the agricultural depression and, like drainage, had to wait until the second world war for its revival.

3. Evaluation

Evaluation of irrigation can be with respect to:

(i) the effect which it has on plant growth,
(ii) farm economics, or
(iii) the efficiency of the field system.

3.1 Agronomy

The systematic approach to evaluation of plant water needs in Britain was largely made possible by Penman's work on the physics of evaporation first published in the late forties, and the associated statistical studies of potential evapotranspiration and rainfall in Britain by the Meteorological Office. Crop responses to irrigation have been investigated since the nineteenth century but methodical studies in this country mainly date from the early fifties. By 1962, the National Resources (Technical) Committee was able to give detailed information on the response to irrigation of the majority of crops grown in Britain but pointed out that more controlled experiments were needed. Today, eleven years later, information on crop responses is reasonably plentiful. Two parallel streams of investigation are discernible.

One approach was to study plant response to full irrigation, generally by bringing the soil moisture status back to field capacity whenever the soil moisture deficit reached some specified level. Putting this work into the context of farm practice there is the implication that it is the responsibility of the Government through the agencies of the river authorities to ensure that sufficient water shall be available when needed.

The second approach started with the more realistic assumption that water available for irrigation was likely to become increasingly restricted and therefore experimentation was directed towards finding techniques for maximising crop response to limited supplies of water. The procedure was to apply water at different stages of plant growth and so determine those stages at which moisture stress affected yield of the useful part of the plant. The results of these studies are summarised in the *MAFF* Short Term Leaflet 71 (Revised 1970).

3.2 Economics

Detailed economic evaluation of irrigation is dogged by uncertainties in the input data. The design life of equipment is in the region of ten to twenty years but the actual life varies widely depending on the degree of misuse. Initial costs are straightforward but running costs — fuel, labour, water, spares — over a ten year span are subject to unpredictable increases. Benefits are even more uncertain. Yields with and without irrigation must be predicted and also the prices at which the extra produce would sell. Who would dare to estimate the price tomatoes will fetch in September 1983? Increased yields depend not only on the shortfall of rainfall relative to plant water requirements, but on when in the growth cycle that shortfall occurs, on the soil type and structure, on nutrient availability — in other words, on the total plant environment. In short, long term evaluation of irrigation is open to the wildest errors.

There have however, been many useful studies of the short-term economics of irrigating specific crops. The 1962 Natural Resources (Technical) Committee Report gave comprehensive information on capital and running costs of various types of equipment, on amounts of water likely to be required, and on the increased values of crop yield to be expected. The response of many crops to irrigation is so marked that a short-term economic study is sufficient to show a significant financial advantage in its practice. Such a study avoids prediction of life of equipment, costs of labour at some remote date, and so on. It is unfortunate that the data on equipment costs and farm prices for produce are essentially ephemeral and need updating annually.

3.3 Field systems

It is virtually impossible to achieve perfection at the drawing board stage of a field irrigation system. The design engineer produces a system and specifies a schedule of operation which will work reasonably well. Much of his input data is approximate with regard both to hydraulics and to the conditions of operation. He frequently has to design a flexible system which can be adapted to different crops, water demands which vary month to month, and a labour situation which changes from year to year. The system which is handed over to the farmer is one which can work well but which needs tuning and keeping in tune.

Evaluation procedures for commissioning sprinkler systems are described in detail by Merriam (1967). Pressures through the pipe network, rates of sprinkling, uniformity of application, wind effects, all need checking. Field tests in which pressure, nozzle size, and sprinkler spacings are varied can be used to show the best combination. Periodic checking of the system while in regular use detects deterioration of components and maintains the standards of accuracy of water application which are assumed.

Soil moisture needs to be monitored if the performance of the irrigation practice is to be known. Scheduling for effective irrigation depends on knowledge of the soil moisture status. Without testing soil samples augered up from different depths within the root zone, the irrigator can only guess at the soil moisture deficit, the soil suction, the depth of water applied, and the depth of wetting, and without knowledge of these factors his irrigation is a very crude business. At its simplest soil testing is by feel, though the more sophisticated methods of using tensiometers or resistance blocks have been used in farm practice. The numerous other methods of measuring soil moisture tend to be appropriate to research work rather than the commercial field. An alternative technique is by the observation of some part of the plant for indication of moisture stress. The rate elongation of sugar cane, for example, has been used in conjunction with normal water balance sheets for control of irrigation scheduling.

Hydraulic and agronomic evaluation on commissioning and in use are an essential part of properly managed field irrigation.

4. Research and practice

There is undoubtedly a gap between research and practice — a gap of twenty years has been suggested by one experienced research worker. Information on crop responses and moisture sensitive phases is readily available but applied crudely if at all. The first reason lies perhaps in the very success of irrigation, the dramatic nature of crop responses. If somewhat rough and ready irrigation produces good results, the additional advantages of carefully controlled irrigation are not readily appreciated, and it may be felt that the extra cost and effort are not worthwhile. A second reason may lie in the problems of management. Although the irrigator may be aware of the advantage of irrigating at a particular stage of crop growth, he still has to reconcile this with the need to cover the area of that crop by rotation, to fit in with the irrigation of other crops, and fit in with all other farming activities. In short he has to make a compromise between the research workers' findings and the exigencies of his complete farm system.

The benefits of field evaluation can be readily demonstrated, but it is rarely seen in practice in Britain. If a manufacturer states that a given arrangement of his equipment delivers 6 mm (0.24 in)/hour, that figure tends to be taken in practice regardless of the ravages of age. Field checks on pressures and equivalent rainfall rates are rare. Measurements of soil moisture below the surface do not appear to be common practice, not even by feel testing augered samples. The varying significance of a given soil moisture deficit applied to different soils and plants of different rooting habits does not appear to be clearly understood. Again, it is probably the success of approximate irrigation which leads the general practitioner to underestimate the benefits of precision.

5. Trends in research

As mentioned previously, Penman's early work leads to numerous experiments on plant response to water. These were of immediate potential benefit to agriculture but, like a butcher's cleaver in an operating theatre, though useful were none too precise. They tended to raise as many questions as they answered, transferring the problem from consequence of irrigation to cause of response. Plant growth depends on a multiplicity of interrelated variables describing the total environment, soil and climate, nutrients and water. To single out one parameter, water availability, for a response function is to set aside the interrelationships and risk ending up with results of limited applicability. As one might expect, research organisations, having built up a considerable fund of knowledge on the direct response of crops to water, have moved their interests towards more fundamental problems — the physics of water movement through the plant; the interaction of water, nutrients, climate, and land management practices — while still continuing straightforward irrigation experiments in some cases. To illustrate the trends the irrigation work at two research establishments is outlined below.

5.1 At the Grassland Research Institute, early work on the response of white clover and various grasses to irrigation was followed by studies of the moisture extraction patterns of roots and on economy of water use by relating irrigation to nutrient availability. Current work includes research into (a) water movement through the plant, (b) grassland management practices, (c) loss of nutrients to drainage, and (d) the effects of poaching by cattle. Also in hand is a revision of earlier work on the water requirements of fodder crops.

Work on potential gradient through the plant has already demonstrated the effects of climatic water demand in limiting the growth of grass. Irrigation, by reducing soil moisture tension, can extend the period of the day during which growth occurs but cannot itself counteract the effect of high air temperature and low humidity.

Work on management practices is concerned with the relationships between the rate of growth of grass, its nutritional value, and the time of cutting or grazing. With the high stocking rates which can be accommodated on irrigated and fertilised grassland, a high standard of management is critical to success.

5.2 At the National Vegetable Research Station, studies on the moisture sensitive phases of crops have given way to work on the fundamental issues; reasons why the relief of moisture stress causes increased plant growth, the nature of movement of nutrients and water in the soil, and the mechanism of water intake by roots. Plant response studies have been expanded to include the total effect of soil, climate, and nutrients, and a mathematical model is being formulated. On the soils side, there is continued interest in the improvement of the moisture holding characteristics of sandy and clay soils.

6. Comment and conclusions

There exists scientific knowledge of the effects of irrigation which, though far from complete, goes well beyond the current demands of field practice. The real problem appears to be that of translating crop water requirements into terms of operation of field equipment while accepting restraints on the use of water and labour. This is not an area for research but rather for the systems analysis of each individual case by the farmer himself or a consultant.

The decline or irrigation of grassland has probably been influenced by numerous circumstances, economic, climatological, and psychological. It is possible that the need for careful management to harvest the benefits of irrigation is not always appreciated. Current research will almost certainly emphasise this point.

Irrigation in Britain is sprinkler irrigation. This was not always so. Surface irrigation of grassland once covered 600 000 ha (1 482 630 acres), but died out because of the difficulties of maintenance of the field channels and the inpedance they caused to farm machinery. Surface irrigation is used widely overseas in conjunction with intensive mechanisation and might well be adapted to British conditions in preference to the great rain-making machines which are appearing in our fields.

Irrigation is only one method of maintaining a low soil moisture tension. There are many other possible ways of achieving the same end, depending on the circumstances. To give examples:

(i) To increase the moisture holding capacity of the soil so that more moisture is available at low suction. Experiments on the inclusion of pulverised fuel ash have been in progress at the *NVRS* for several years.
(ii) To reduce evaporation by shelter belts or other means. This was advocated in 1851.
(iii) To increase infiltration of rainfall by amended cultivation or surface treatment practices.
(iv) To improve drainage and so increase rooting depths.
(v) To restrict drainage in summer and so create a perched water table and effective sub-irrigation.

In a situation where water shortage is certain to develop, the only uncertainty being the time scale, it would be wise to consider alternative, and cheaper, means to improving the soil moisture environment of plant roots without irrigation.

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Trends in Irrigation Development Overseas*

by P. H. Stern MA FICE MIWE†

Summary

THE paper reviews the historical development of modern irrigation, starting in India in the nineteenth century. The growth of areas under irrigation in the world in the two decades 1950–70 are then described in tables, which show that nearly two-thirds of the world's total continues to be found in South-East Asia.

Significant recent trends in irrigation development are (a) the extension of irrigation from truly arid to less arid areas and a greater diversity of crops, fruit and vegetables irrigated, and (b) a move in favour of overhead irrigation, where this is technically and economically feasible. Management, however, continues to be a problem in most of the developing countries.

The paper concludes with a brief description of two recent large-scale irrigation developments, one in Rumania and one in Malawi.

Introduction

Irrigation has been practiced traditionally in some parts of the world for many centuries and is associated with the civilisations of China, most of South East Asia, the Indo-Gangetic plain, the Tigris-Euphrates plain and the Nile Basin. In overall layout, many of these ancient systems have continued until the present. Water supplies were for the most part unregulated and uncontrolled, and the distribution and amounts of water available for crops each year varied considerably with rainfall and run-off.

The first efforts to introduce modern engineering to irrigation took place in India during the nineteenth century, followed quickly by large-scale developments in the Southern United States. During the first half of the twentieth century, mainly under the influence of the French and the British, traditional irrigation systems in many parts of the world were modified and improved. The most significant feature of these works was the development of the river barrage and canal headworks which ensured a much more efficient and effective diversion of river waters, and which allowed water not required for irrigation to pass on down the river. Many of the now well-known barrages in Pakistan, India, Egypt and Iraq were built during the first 20–30 years of this century. At about the same time engineering was being introduced into the already very extensive rice irrigation systems in Malaya, Indonesia, and other parts of the Far East.

Usually, as modifications and improvements were applied to irrigation systems serving largely peasant agricultural patterns, government responsibility exercised through irrigation departments and services, was confined to head works and major distribution, and little was done to carry improvements down to field level where efficiencies were often very low. But even with low efficiencies most of these developments showed positive economic returns to the governments which were responsible for them, and at the same time did much to improve the food situation in rural areas. R. B. Buckley, in a classic work on irrigation in India[1], wrote in 1919: 'The beneficial results which both the security and the increase of out-turn (ie crops) confer on the people are incomparably more valuable than the large revenue derived by the State'.

Meanwhile in the United States, and under commercial enterprise in other parts of the world, irrigation technology was being advanced at all levels, including engineering improvements to minor distribution systems and field water applications. The 1920's and 1930's saw the development of the high efficient Dutch sugar cane plantations in Java, and the Gezira scheme in the Sudan for cotton, dhura and animal fodder. The state of many parts of the world at the end of the 1939–45 World War gave a fresh impetus to food and cash-crop production, and consequently to irrigation. Techniques evolved in the United States and in the older irrigation countries were being tried in many new situations, in Africa, Australia, Europe and South America.

The improvement of benefits from irrigation at the farm level has been the concern of the Food and Agriculture Organisation (*FAO*) of the United Nations for many years, and this subject has often been discussed at its regional conferences. In October 1970 *FAO*, with financial support from the United Nations Development Programme, and in co-operation with the Government of the Philippines, organised a seminar on this subject for the countries of Asia and the Far East[2]. Among other things this seminar concluded (a) that more attention should be given by governments to small-scale development, and (b) that while the economic feasibility of a project needed to be assured, sociological considerations should not be overlooked.

Irrigation areas

By the 1950's nearly 120 million ha of land in over 70 countries was being irrigated. In 1972 this had increased to over 200 million ha in 100 countries[3]. Table 1 summarises areas under irrigation by regions in the years 1952, 1963, 1970 and 1972 with a forecast for 1975 based on data collected by the International Commission on Irrigation and Drainage.

Table 1 Irrigated areas in the world, 1952 to 1972 and forecast for 1975

	Million ha				
Region	*1952*	*1963*	*1970*	*1972*	*1975*
1. Africa	4.2	5.5	6.4	6.6	7.0
2. Australia and New Zealand	0.6	0.8	1.3	1.4	1.5
3. Caribbean & Central America	2.2	3.3	4.1	4.9	5.3
4. Europe	6.1	9.6	12.2	13.0	16.6
5. Middle East	6.5	8.5	10.7	10.9	12.2
6. North America	10.9	13.9	17.6	17.6	19.1
7. South America	1.4	2.4	3.7	4.5	5.2
8. South-East Asia	79.2	97.8	131.8	132.0	137.8
9. USSR	6.0	8.0	9.9	10.4	12.5
World Total	117.1	149.8	197.7	201.3	217.2

Table 2 shows the percentage distribution of irrigated areas by regions for the years 1952 and 1972 and the increases in irrigated areas from 1952–72 expressed as percentages of the areas in 1952.

It is interesting to note that the greatest rates of increase occurred in Latin America, the Caribbean, Australia and New Zealand, although these countries together account for only just over five percent of the world total of irrigated land. South East Asia still contains most of the world's irrigated land, nearly two thirds in 1972, and 67% more than in 1952. The countries of Africa, late starters in the irrigation field (except of course for the United Arab Republic), are developing only slowly, and account for slightly less of the world total than they did in 1952.

Except for a general growth throughout the world these statistics do not demonstrate any particular trend in the types of growth. Perhaps the most significant development has been the change in

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Table 2 Percentage distribution of irrigated areas, 1952 and 1972, and percentage increase from 1952 to 1972

Region	1952 %	1972 %	1952–1972 % increase
1. Africa	3.6	3.3	57
2. Australia and New Zealand	0.5	0.7	130
3. Caribbean and Central America	1.9	2.4	123
4. Europe	5.2	6.5	113
5. Middle East	5.6	5.4	68
6. North America	9.3	8.7	61
7. South America	1.2	2.2	221
8. South-East Asia	67.6	65.6	67
9. USSR	5.1	5.2	73
World	100.0	100.0	72

concept of the irrigation need criteria. Until about 1950 irrigation was practised in lands where either rice was grown traditionally as a flooded crop or rainfall was insufficient for any reliable cultivation. Today irrigation is applied under a very much wider range of rainfall and climatic conditions. Thus we find 13 million ha of land irrigated in Europe, more than double that in 1952, while many countries with relatively good but seasonal rainfall are adopting irrigation to extend cultivation seasons for multiple cropping.

Irrigation supplies

Fifty years ago irrigation water was supplied to the land through surface distribution systems in open channels by gravity flow. Gravity flow was provided by river control works such as the barrages described earlier in the paper, and pumping for an irrigation supply was often ruled out on grounds of cost. Today pumping is a common feature of irrigation in many parts of the world. Pumps may be used (a) to extract water from a source, (b) to provide a second or third stage lift to reach higher ground, and (c) to pressurise water for overhead irrigation systems.

Pumped sources of supply may be developed from rivers or lakes or from underground. Large pumped supplies are usually delivered to open canals for conveyance to the cultivation areas, but large diameter pipes are also used. Stage lift pumping is a common feature of large gravity supply developments where the cultivable land lies at different levels. There are many different systems of pressure pumping. In some cases, where the water source is conveniently near to the cultivated land, water can be pumped straight in the pressure system.

An interesting development concerns the use of saline water for irrigation. Research in the United States in the 1930's led to the conclusion that water containing salt concentrations about 2000 mg/litre was not suitable for irrigation[4]. In recent years techniques have been developed in Israel[5] and in Tunisia[6] where water with salinities up to 6000 mg/litre has been used successfully.

Irrigation methods

In 1964 the Greek National Committee of the *ICID* addressed a questionnaire to all member countries on trends in irrigation development[7]. Thirty two countries replied and an analysis of their replies led to the following conclusions:

1. Both surface and overhead irrigation methods had their relative merits, depending upon a number of variable factors.
2. Large irrigation schemes used mainly open channel distribution systems, and only in special circumstances were piped main supplies preferred.
3. Overhead irrigation methods were growing in popularity, particularly in more developed countries, since they made it easier to use optimal amounts of water and were therefore more economic.
4. Surface methods were, however, still preferred where saving in operating costs was paramount, where it was difficult to modify existing systems or to change tradition, or where rice was grown.
5. Overhead irrigation methods were favoured where topography was unsuitable for surface methods and frequently in new developments on land not previously irrigated.

There has not been a more recent survey, but it can be said that, today, trends are very similar, with greater use of piped supplies and overhead irrigation systems.

One feature which has appeared in the past decade is the introduction of automation in irrigation control systems. Automation is now being used for the regulation of water levels and discharges in open-channel distribution systems, and in the operation of pressurised pipe sprinkler layouts. In situations where capital investment and economic returns are high and where labour is expensive, this is a rational development. The case for the introduction some years ago of automation into a large distribution system for rice in Malaya is not so obvious. Labour-intensive economies generally do not benefit from systems which eliminate labour.

While most of the large-scale irrigation schemes in the world are either surface or overhead schemes, with a growing popularity for overhead systems for sugar cane and tree crops such as tea and coffee, low pressure piped supplied are being developed for small-scale cultivation, in market gardens and in greenhouses.

The techniques of trickle irrigation are being developed in Israel[8]. Here water is applied to crops through perforated pipes laid at ground level or just below the surface. Trickle irrigation requires little more water head than surface gravity irrigation, and therefore avoids the relatively costly pressure pumping needed for overhead irrigation. Trickle irrigation has also the advantage of enabling plant nutrients introduced into the irrigation water to be applied just where they are needed, under accurate control and without wastage.

Management

Management is often a critical factor in irrigation schemes, and where management is a problem, small-scale irrigation development has distinct advantages. For many years there have been numerous successful small-scale private or communal pump irrigation schemes on the Nile in the Northern Sudan, and on the Tigris and Euphrates in Iraq. While enormous sums of money have been spent on unsuccessful large-scale projects in Bangladesh††, the current programme of small-scale development with large numbers of small low-lift pumps is achieving a measure of success.

In time, with the advance of education and training, and as individual farmers or groups of farmers evolve their own effective systems of management, it is to be expected that in the future there will be less need for the large centrally controlled government scheme. A government authority or public agency may still be responsible for the irrigation supply, but will have less control over its use.

Crops

Another feature of irrigation trends today is the extension of the range of crops irrigated. This development is concurrent with the extension of irrigation over a wider range of climatic conditions, so that today there is hardly a food crop, cash crop, vegetable, fruit or tree crop which is not irrigated somewhere in the world. The development of overhead irrigation through piped supplies under pressure has enabled any crop on any terrain to be reached by irrigation, including hill crops such as tea and coffee.

Two overseas projects

Two recent overseas projects in which British technology has been involved will now be described briefly. Both are large-scale developments and each contain some interesting technical features. The Sadova-Corabia Project is a comprehensive multiple cropping development in Rumania, and the Nchalo Sugar Project is a large-scale sugar-cane enterprise in Malawi.

The Sadova-Corabia Project

This project is a 70 000 ha development for maize, lucerne, vines, orchards and some vegetables, being undertaken by the Government of Rumania, with British participation with finance, engineering and equipment under a counter-trade agreement. The project is currently under construction.

Overhead irrigation is being used throughout, the main water supply being pumped from the Danube River. The main pumping station with a capacity of 44 m^3/sec, lifts the water 70 m in 3.65 m diameter pipes 4.5 km long. This feeds a first level gravity distribution system, with a second-stage lift of 26 m capacity 24 m^3/sec to reach higher land, also served by a gravity distribution system. Some areas in the river flood plain are served by separate pumping stations.

††In the 10 years between 1960 and 1970 nearly £120m had been invested in land and water development projects, producing tangible benefits to some 60 000 acres.

Pressure pumping stations for overhead irrigation, each serving blocks of about 530 ha, are located on the gravity distribution systems. The irrigation supplies are controlled automatically by variations in pressure in the pressure systems, changes in pressure controlling both the pressure pumping stations, and regulating weirs on the gravity canals.

Overhead irrigation is designed for 24-hour operation during the irrigation season from March to October. The portable equipment, of various types, is handled by the farmers, who operate the irrigation hydrants manually.

The Nchalo Sugar Project

Sugar cane is being grown commercially at Nchalo, in the lower Shire Valley, by the Sugar Corporation of Malawi, a subsidiary of the firm, Lonrho. The Project, which started in 1965, had developed a planted area of 1700 ha as a first stage by the end of 1966. At present the development consists of about 5000 ha, increasing to 6000 ha in 1974.

Irrigation water is pumped from the Shire River. For stage 1 (1700 ha) pumps on the river bank deliver straight into a pressure pipe system. For subsequent developments low-lift pumps feed concrete-lined open canals, pressure pumps being suited in pairs along these canals. The pressure supply is carried in underground mains to hydrants for connection to the portable equipment. All pumps are electrically-driven with power supplied from the Tedzani Falls Hydroelectric station.

Low discharge sprinklers are used, with two 11-hour sprinkler settings in 24 hours, during periods of peak irrigation requirement. This requires one portable pipe movement every 24 hours and one subsequent sprinkler move along the pipe.

Acknowledgements

The author expresses thanks to Mr J. A. N. M. Holt of Binnie and Partners for information about the Sadova-Corabia Project and to Mr G. Hay of Wright Rain Ltd, for particulars of the Nchalo Sugar Project.

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INSTITUTION OF AGRICULTURAL ENGINEERS

Penn Place Rickmansworth Herts

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Equipment Available for Use in Agriculture and Horticulture in the United Kingdom*

by J. Ingram NDH

Summary

INCREASING labour costs, along with the disruption caused to the farm day by the need to move irrigation equipment and a general dislike of the work from the operator's point of view, have all contributed to the increasing trend for irrigation methods to move away from labour intensive systems to capital intensive ones. Equipment development has progressively reduced the labour element resulting in the large boom irrigators that are now being used for extensive irrigation.

Similarly equipment for the fruit grower is evolving towards a solid set system using either (a) overhead rotary sprinklers providing the additional valuable function of frost protection or, (b) the more recent trickle systems which are now being introduced.

Irrigation equipment in the glasshouse has reached a very high level of development and with associated heating and ventilation provides a closely controlled environment under automatic control.

Field irrigation systems of the future may well develop on solid set lines with underground pipework and large sequencing sprinklers.

Perhaps it should be asked at this time whether competition within the irrigation industry is starving manufacturers of the funds that might be devoted to more research and development.

The following brief assessment can be made of the present range of irrigation systems available, together with approximate costs and labour input. In-field costs are given, excluding pumps and mains.

1 Conventional layout of rotary sprinkler lines

While capital cost is low, there is a high labour requirement to cover the 3–4 moves per day of all the equipment.

Cost: approx. £380 for 1 acre of 3 in equipment working over 30–40 acres on a 10 day cycle = £12–£15/acre

Labour: 2.3–2.5 man hours/acre inch.

2 Conventional layout with alternate sprinkler positions

(eg Farrow 'Risermatic', Wright Rain 'Hopalong')

Simplifies the labour requirement by needing only one movement of the pipes each morning; subsequent movement on the day is of sprinklers only. The sprinkler standpipes are fitted into automatic closing valves which shut off when the standpipe is removed. With a two position arrangement, sprinklers are placed in each alternate outlet and are moved down one outlet to the second position later in the day. With a three position arrangement, a sprinkler is placed in the first outlet position followed by two outlets without sprinklers and so on. Each sprinkler is then moved down to the second outlet at, say, lunch-time and to the third outlet at, say, tea-time. Switching off can be done automatically in the evening. The pipes are again moved over on the following morning.

Cost: approx. £290 for 1 acre of 2 in equipment working over 10 acres on a 10 day cycle = £29/acre

Labour: 1.5–2.0 man hours/acre inch.

Institution of Agricultural Engineers Autumn meeting, at NCAE, Silsoe, on 27 September 1973.

†Deputy Director, Luddington Experimental Horticulture Station.

3 Semi permanent lateral grid with sprinklers moved

(eg Farrow 'Cropset', Wright Rain 'Portagrid')

Comprise small bore laterals of 1¼ in diameter which are placed in position for duration of crop. Each lateral is connected by flexible hose with quick couplings to the headland main permitting the main to be easily moved away for tractor traverse. The sprinkler standpipes again fit into automatic valves and two sprinklers are used per lateral, one commencing at the beginning of the line and the other commencing half way down. The sprinklers are then moved progressively down the lateral.

Cost: approx. £120–£150/acre

Labour: 0.75 man hours/acre inch.

To eliminate the need for hand movement of the sprinklers with this system a hydraulic sequencing valve is under development. With this arrangement a full set of sprinklers is required each fitted with a sequencing valve and the valves are actuated by a fall in the water pressure. These 'pulses' are produced by a timer operated master valve in the mains supply. The cam wheel in the sequencing valves can have a varying number of lobes to provide different frequencies of valve opening.

4 Solid set systems

(a) Permanent or semi-permanent installations in fruit crops, particularly blackcurrants and apples, for frost protection and irrigation. The capital costs are high and considerable quantities of water are required as the entire area has to be covered with equipment and the sprinklers have to be kept in continuous operation during periods of frost. Sprinklers are spaced in an equilateral triangle arrangement and need to apply 1/8 in/hour to provide a 9°F temperature lift. Large pump capacity and adequate water supplies are necessary to provide for the 47 gal/min/acre water requirement. However, precipitation rates of 1/16 in/h can give equivalent protection providing the droplet size is small but this entails much closer spacing of sprinklers and considerably increased capital costs.

There has been interest in the possibility of increasing the use of solid set systems of this kind as multi-purpose installations for the application of spray materials, nutrients, residual herbicides and possibly growth regulating materials, in addition to the basic use for frost protection and irrigation.

In effect the sprinkler replaces the need for tractor operations within the crop and the culture of blackcurrants in this way has been demonstrated at both Luddington EHS and Long Ashton Research Station. Pest control and the application of nutrients and the residual herbicide simazine have been successful but control of underleaf disease has been inadequate. Good cover of the upper leaf surfaces is achieved from sprinklers but underleaf cover is poor, a

Metric units have not been included in this paper since the Imperial system is still widely used for sprinkler equipment specifications, particularly in the United Kingdom.

problem that could be resolved with the introduction of a good fully systemic fungicide.

There is a need to apply the spray materials simultaneously from all the sprinklers and avoid subsequent washing off with clear water. In developing the concept of the 'Meadow Orchard' where overall application by sprinkler system would be useful, Long Ashton Research Station have devised a 'Hartley' pipe layout which ensures that each sprinkler is equidistant from the pesticide injection point and pipe diameters reduce by half each time the flow divides by four.

This application of materials through sprinklers would be facilitated by the introduction of sequencing sprinklers and might then find wider application if costs can be kept down to an acceptable level.

Cost:[1] Solid set sprinkler system with sprinklers at 80 ft X 70 ft spacing £230/acre; at 60 ft X 50 ft spacing £260.

(b) Various 'solid set' systems are in use for the irrigation of hardy nursery stock using sprinkler heads such as the 'Rotoframe'.

(c) **Trickle irrigation**

Trickle irrigation can be considered as a form of 'solid set' installation.

Of the methods available for irrigating crops such as apples, the use of conventional portable equipment is losing favour because of the increasing labour costs and the difficulty of moving pipes through modern close plantings. 'Solid set' *sprinkler* systems eliminate the labour need and, as previously discussed, provide additionally a means of frost protection and may also be used in the future for the application of pesticides, but capital costs are high and considerable quantities of water are required.

For a limited range of crops such as apples, pears, plums, cherries, raspberries and possibly hops, trickle systems may well offer us a means of placing the right amount of water in the right place at the right time, at reasonable cost, with the minimum of labour requirement and the most efficient use of water. Installation costs escalate with crops at closer row spacings. Only a small area of the soil surface in the vicinity of the 'dripper' is wetted reducing evaporative losses and this, together with the more accurate placement of water, can lead to claimed water savings of 50%.

The trickle method involves the use of small bore plastic piping of 3/8–1/2 in or more diameter with 'dripper' outlets arranged at intervals of 4 ft or so along the line. A wide range of 'dripper' outlets are available from simple 0.035 in microtube which can be cut to varying lengths to achieve uniform output over sloping land to self compensating emitters that automatically ensure uniformity of water output. Application rates per 'dripper' range from one pint to one gallon per hour calling for a flow of 50–400 gallons/acre hour at 400 'drippers'/acre. While some of the systems work at very low pressures of 2–4 lb/in^2 15 lb/in^2 is more usual. Adequate filtration is essential to avoid problems of blockage of the 'drippers'.

Cost: £40–£100 acre in an 18 ft X 12 ft planting = 200 trees/acre X two 'drippers' per tree.
At closer row spacings for raspberries, costs would be £80–£200/acre.

Large self propelled units

For extensive irrigation the development of large mobile boom irrigators and rain guns has enabled irrigation to proceed without attention over long periods.

5 Irrianglia linear boom irrigator

This irrigator covers about 400 ft in one pass and comprises a non-rotating boom mounted on a 4-wheel chassis driven by a small diesel engine. Ten travel speeds are possible which, with a choice of nozzle sizes, gives a range of application rates. Water supply is by way of a high pressure flexible hose and the machine can pass over a distance of 1300 ft at one move following a furrow (which need not be straight) and under the control of a powered steering device. It can irrigate about 12 acres at one setting.

Working pressure 50–60 lb/in^2 at the nozzle and water requirement is 400–600 gal/min.

Cost: £4500 including 660 ft of flexible hose.

6 Laureau system – Wright Rain

Consists of a three wheeled unit powered by a petrol engine, the outer wheels being adjustable between 7.2 and 12 ft to suit row spacings. A central pivot carries the main boom assembly which rotates once every 1½–2 minutes applying water at 0.25 in/hour and giving a circular water pattern. The unit is stationary when irrigating and is moved between settings. Racks on the unit carry up to 65 5 in X 30 ft aluminium pipes for use as portable feeder main.

The largest model L 150 gives an effective coverage of up to 2.9 acres per setting with a spacing of 360 ft between operating positions. With four settings per day 11.6 acres may be irrigated with an in-field labour commitment of 1 hour for 2 men. Working pressure at the booms is 80–85 lb/in^2 and a water requirement of 275 gal/min.

Model L 130 covers two acres at a setting with a spacing between settings of 295 ft and water requirement of 200 gal/min giving an application rate of 0.25 in/h.

A small tractor mounted model, the L 110, is also available and is capable of irrigating up to 50 acres in a 10 day cycle. Coverage is about 1¼ acres per setting with a spacing between settings of 236 ft and a water requirement of 145 gal/min giving an application rate of 0.27 in/hour.

Cost: L 150 £3466 + 300 yards 4 in or 5 in pipe
L 130 £3275
L 110 £1357

7 Rainamatic self travelling sprinklers – Farrow

The Rainamatic Two/90 is a five acre/day self propelled irrigator. Equipped with 600 ft of pipe it can travel 1200 ft by winding its hose up to a central point and then feeding it out again. An area 1200 ft X 180 ft can, therefore, be irrigated in a single pass. Applying 1 in this represents 22 hours of continuous and unsupervised irrigation. The unit can also be supplied with 900 ft of supply pipe, permitting an 1800 ft traverse. Water requirement is 85 gal/min with the sprinklers operating at 50 lb/in^2.

Water pressure driving a winch propels the unit along and the 4-wheel carriage has ample adjustment for row crop widths. Water distribution is by a full circle sprinkler on the end of each boom and 2 centrally positioned part circle sprinklers.

The Rainamatic Series One/30 is a smaller unit working on similar lines capable of applying 1 in over 2 acres per day = 20 acres on a 10 day cycle.

Cost: Rainamatic Two/90 2 in £2000 approx.

8 Rainamatic dolphin travelling rain gun – Farrow

This is a carriage mounted rain gun which pulls itself along by means of a water powered winch. The rate of travel can be controlled and the total length of run is up to 436 yards. The collapsible hose supply is dragged behind the traveller.

Cost: Model Three/200 £2400 approx.
Model Four/400 £2800 approx.

Acknowledgement

Information kindly supplied by J. Robertson, *ADAS* Mechanisation Adviser, Cambridge, and by the irrigation manufacturers is gratefully acknowledged.

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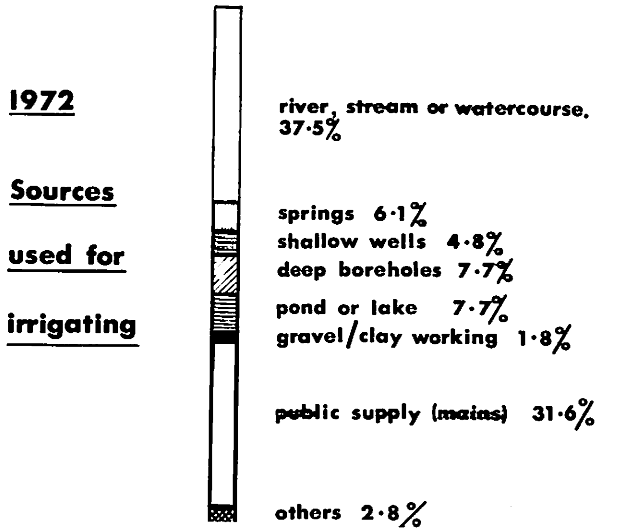
Irrigation supplement *Farmers Weekly*, 9 Feb. 1973.

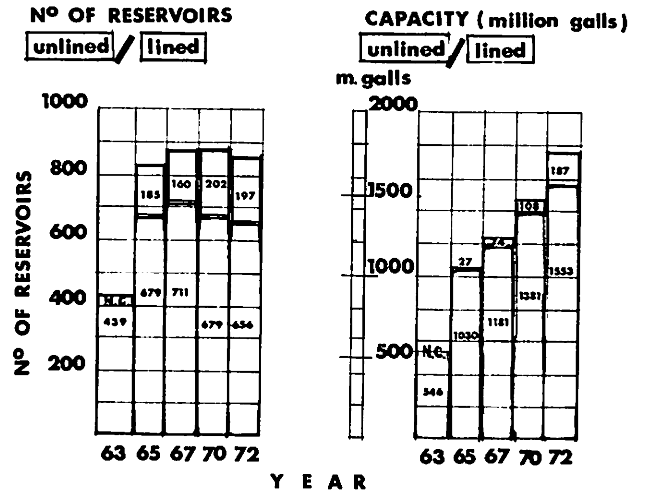
IRRIGATION FOR AGRICULTURE AND HORTICULTURE IN THE 70's

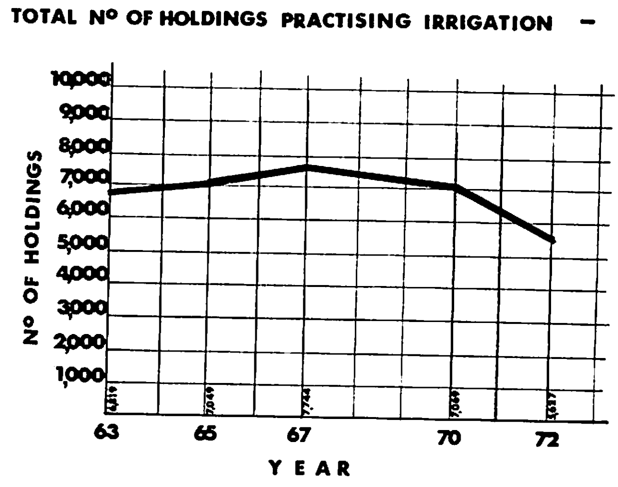
Edited summaries of discussion

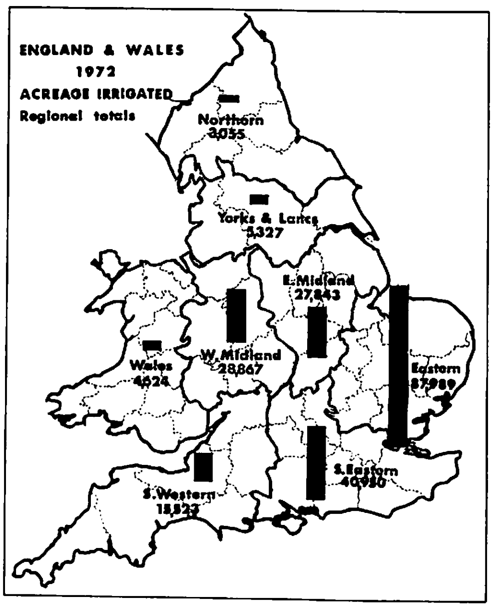
Papers 1 & 2 by Messrs Comyn and Huntingdon

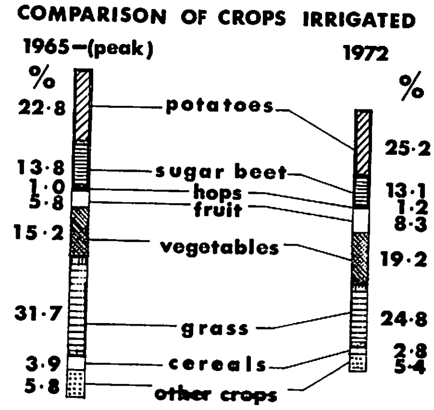
Mr C. N. Prickett *(MAFF,* London) said that the Ministry was in a position to observe the overall scene of irrigation and to collect data from which it may be possible to predict future trends. To illustrate this point he showed diagrams, reproduced below, of statistics from 1955 to date. He said that a carefully prepared scheme would essentially start with a feasibility study, make full use of available scientific and engineering information, and proceed to a complete design of source and hardware. Even then any irrigation scheme needed lots of effort on the ground if it were to work properly. Mr Prickett considered that irrigation use would grow, particularly as the Government grant is still at 20%, and he posed the question as to whether improvements could be made to Ministry publications by breaking down the present composite handbooks into a series of smaller, self contained sections. It would be interesting, he said, to hear from the authors their ideas as to why the rate of increase in irrigation had slowed down.

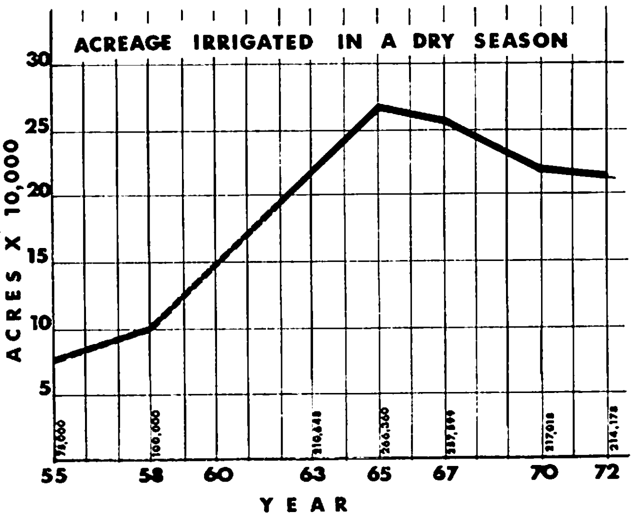












Dr H. L. Penman (Rothamsted) pointed out that although the amounts of water evaporated by potatoes and cereals during their growing seasons referred to in Mr Huntington's paper were generally accepted, the water requirement for these crops is approximately the same. It should be remembered that potatoes at harvest contain about 75% water.

Referring to fig 2 in Mr Huntington's paper, he stated that the form of response indicated was originally put forward by himself in 1946/47 based on experiments conducted on the rate of evaporation from bare soil. He also mentioned that the 1972 Rothamsted Report includes a ten year survey of water use by unirrigated and irrigated crops stating the differences and giving details of end of season recharge requirements.

Commenting on Major Comyn's paper, Dr Penman expressed disappointment that no information had been included about actual amounts of water applied to crops during particular seasons. He was also concerned that water requirements were also overestimated in Major Comyn's experience. He was most interested in the use of the phase 'true' water requirements of crops, but wondered whether this would ever have real meaning until we could introduce similar phrases such as 'true' rainfall for the area! Even if it were possible to define the true water requirements it would be necessary for efficient operation to manage crops eg potatoes such that only the true water requirement was used. The ridging system developed originally to get rid of excess water, whereas in the absence of ridges less water would be needed.

Major J. A. Comyn apologised for the lack of detail on irrigation applications but felt that even where data was available they would not appear to be particularly enlightening. He confirmed that less water was used than recommended but reported that he was working to figures put forward by Dr Penman.

Mr D. W. R. Evans (Director, Lord Rayleigh's Farms Inc. and Strutt and Parker (Farms) Ltd) referred to the difficulty of putting a real value on the benefits of irrigation. Examples of this aspect included the possibility of lifting potatoes with less damage and of reducing the total acreage of grassland for cattle. He also mentioned that there are a variety of problems still to be solved in respect of use of water on the land. It is not known for example at what stage plants begin to suffer through lack of water and hence at what stage in the growth cycle irrigation is required. Factors such as management, labour and weather are clearly vital in this respect. Potatoes were once irrigated in his organisation to within 12 mm (0.47 in) of field capacity only to be rapidly followed by 36 mm (1.42 in) of rain; the results were disastrous.

Mr Evans could not agree with Dr Penman's suggestion that only small amounts of water reached potato roots under the ridging system and considered from practical experience that if water did not significantly penetrate to the roots then the roots would move to the water. He suggested that the use of a 0.9 m (36 in) baulk with flatter ridge tops gives better results from the irrigation point of view than a pointed ridge at 0.76 m (30 in) spacing.

Mr R. Huntington accepted the points made by Dr Penman and stated that in his experience the amount of water being applied by farmers was less than Ministry recommendations. He thought that there were a number of reasons for this tendency and stressed that this fact should be taken into account when designing irrigation schemes. Mr Huntington also suggested that 100 m^3 (3531 ft^3) should be accepted as the unit of volume as being approximately equal to the acre-inch.

Papers 3 & 4 by Messrs Withers and Stern

Dr A. N. Ede (Land & Water Management Ltd) drew attention to the necessity for British operators to keep abreast of work in irrigation overseas, and said that British farmers get a spin-off from the effort put into schemes for other countries. He referred to the fact that manufacturers spend considerable sums on research each year which ultimately benefits British farming, and pointed out that the work done by consultants on irrigation schemes is now part of a large scale agricultural engineering industry. Opportunities for your men in irrigation overseas, in research, manufacture, and equipment use, are expanding and create challenges at least equal to those of colonial times. Dr Ede postulated that if it were possible to bring about five percent change in the areas irrigated by old-fashioned surface methods to convert them to modern sprinkler schemes, then this change in itself would be sufficient to provide food for a further 25 million people. He said that sprinklers provide a far better water distribution pattern, and if correctly operated problems due to salt accumulation need not arise.

Mr D. V. Chambers (Hunting Technical Services Ltd) took up Dr Ede's last point and advised caution in suggesting large scale change-over from surface to sprinkler irrigation without having adequate knowledge of soil characteristics and of the susceptibility to troubles by increasing salinity. He also said that suggested change-over of irrigation methods can create severe field management problems, particularly where small holdings are not really suitable for the large sprinkler machines now in vogue; large scale changes would not be possible until land consolidation took place.

Dr A. N. Ede suggested that water use in the form of surface irrigation has developed because of lack of homogenity in soil, the variation in water intake across a cultivated area being possibly as great as ten to one. He reported that examples exist where sprinkler irrigation has worked successfully, water being applied to within ten percent of mean across the irrigated area. In his opinion salinity problems were being dealt with adequately.

Mr P. H. Stern stated that surface irrigation techniques had been established in south east Asia for many years which made the introduction of new techniques slow and difficult. In Africa, however, where irrigation has not been practiced so extensively work schedules involving new techniques were easier to introduce.

Mr J. F. F. Clarke (Binnie & Partners) considered that Great Britain is peculiar, when compared with world wide agriculture, in that it is a country in which farmers' profit is the real motive for using irrigation. He instanced cases in *USSR* and eastern European countries where the main aim is to get uniformity of yield from one year to another, to provide produce for export and to reduce labour requirements on the land; the irrigation schemes developed thus require a lot of sophisticated automation. With these motives it is accepted that production costs with irrigation will increase, but this is acceptable in many countries. On the other hand there are irrigation schemes purposely designed to be labour intensive so as to improve conditions for settling people, and in this case surface irrigation is to be preferred to automatically controlled sprinklers. Mr Clarke said that it was essential in any irrigation scheme to ascertain the fundamental reasons behind the need to irrigate.

Dr H. L. Penman referred to shelter belts of trees as a means of reducing evaporation from fields, and said that he was of the opinion that very little reduction, if any, would be achieved.

Mr J. Morris (*NCAE*) said that his studies had shown that farmers are usually risk averters and they instal irrigation schemes in order to stabilise and improve agricultural production rather than to maximise it. He said that this aspect must be taken into account when considering the future for irrigation in Great Britain, and the question of what would be the criteria for a sound investment must be answered.

Mr W. B. J. Withers referred to work being undertaken at the Grassland Research Institute on grass growth relative to leaf water potential and total radiation, which may lead to suggestions as to when, or when not, to apply irrigation water.

Paper 5 by J. Ingram

Dr A. Ivenny (Wright Rain Ltd) enumerated several points which the design/manufacturer of irrigation equipment must pay attention to. Briefly these are: automation where labour is expensive or choosy; the improvement of water distribution; attention to the energy requirements of a scheme; ease of servicing and operation; robustness, and competitive cost. He considered that there will be a worldwide expansion of irrigation application from which the British farmer will benefit because of the need to carry out more research and development of equipment and techniques.

Mr J. F. F. Clarke referred to trickle irrigation of the intermittent type which was being used in France. Apertures of a larger size were used in order to overcome the need for stringent filtration. The supply was actually switched off and on between drips – hence the use of the term 'intermittent'. Was there any information of this method being applied between row crops?

Mr Ingram replied that a rate of 0.56 litre (1 pint)/hour was used in some systems which required 24 h operation; 4.55 l/gal/h units were operated for 3 h. Calcium deposits at the outlet were becoming a problem although filtration difficulties had been largely overcome.

The largest schemes being operated in Kent being between five and ten acres. On the subject of capital cost, 4.57 m (15 ft) spacing schemes seemed a reasonable arrangement costing between £40 and £100 per acre. These schemes were mainly used in apples. Vegetables were also suited to this method so were raspberries which could be harvested whilst irrigation was being applied.

Mr J. A. C. Gibb (Reading University) asked for information on present day practice with respect to working pressures in irrigation pipe networks, and what the future trends would be

Mr Rowland Smith (*MAFF*) commented that whereas formerly Class *B* pipes were invariably used, nowadays it was more common to use Classes *C* & *D*, indicating working pressure increases from about 61 m (200 ft) to 91–122 m (300–400 ft).

Mr W. P. P. Farrow (Farrow Irrigation Ltd) stated that his company considered it to be necessary to provide a wide range of machines and equipment to meet the various requirements of irrigators. Consequently British companies could offer equipment for row crops and for tall plantation type crops, solid-set irrigation layouts, and trickle equipment.

Mr G. Beck (*SPP* Agricultural Services) asked for information on the application of fungicides and herbicides through sprinkler irrigation systems – what is the state of the art and how this can be applied in 1974?

Mr J. Ingram said that there were two distinct schools of thought on fertiliser application, and one of these was that this practice represented a retrograde step. However, research work was continuing at both Long Ashton and at Luddington *EHS*, and reports would be made in the future.

Mr A. N. Ede considered that it was necessary to establish a central station from which it would be possible to obtain detailed information on all aspects of irrigation. At present, he said, a number of smaller centres held information and co-ordination between them was haphazard. He wondered whether or not *ARC* should set up a centralised service.

From 1 January 1974; all editorial matter should be addressed to Brian May, Institution of Agricultural Engineers, West End Road, Silsoe, Beds, MK45 4DU; all advertising orders, blocks and copy should be addressed to Linda Palmer, PO Box 10, Rickmansworth, Herts. WD3 1SJ

Sprinkler Irrigation Uniformity and its Effect upon System Design

by G. T. Hay

Capital cost and efficiency

THE choice of equipment and the selection of sprinkler spacing and hence the amount of field equipment required all effect capital and operating costs. The decision to use any particular type of equipment or sprinkler spacing is made on a cost basis and also from consideration of the system efficiency and the uniformity of application of water. Although these factors are closely related it is convenient to deal with them separately. The efficiency of sprinkler irrigation will vary with climate as this effects the level of spray losses by direct evaporation and wind drift. Deep percolation losses also occur when water is applied unevenly or in excess quantities or both. Evaporation losses are a function of air temperature, relative humidity and wind speed. In some cases losses due to advection occur and these must be assessed from experiments or local experience. In the case of normal evaporation losses, methods exist for their determination[1]. It is not universally agreed that the evaporation losses represent a loss of water to a growing crop as during sprinkling the transpiration rate of the crop falls rapidly due to the change in the micro-climate in the sprinkled area and closely adjacent areas[2]. The changed plant environment is partly due to the falling water and to the drop in temperature caused by the evaporating spray. It has been argued that this drop in transpiration should be credited to the irrigation system and not treated as a loss[3,4]. Evaporation increases with wind velocity and allowances must be made for seasonal wind variation in evaporation loss calculations. Wind speed has an important impact on the uniformity of water application and allowances must be made for this factor during the design stage of the irrigation system. It is usual to make an adequate allowance for evaporative losses by increasing the system capacity. This is not done with much precision because of the possible margin of safety which exists because of the effects of local cooling and also other matters may have a greater effect upon efficiency and tend to mask any slight variation in spray losses caused by changing evaporation levels.

The efficiency will be affected by the educational level of operators and their social aspirations, health standards and training. Operating pressures must be set at the correct level and equipment moved at the right intervals if efficiency is to be maintained. These latter factors are not subject to precise measurement and hence a management or operation allowance is made to give some margin.

Thus the magnitude of the efficiency factor used during the irrigation planning stage can depend upon the subjective reasoning of the designer and other measures which it is thought can be used to mitigate the effect of lowering efficiency. These considerations have a much greater impact on overall irrigation system efficiency under normal conditions than do evaporation losses. Standby equipment may be cheaper than increasing system capacity as will flexibility in labour usage, prudent preventive measures taken against likely crop pests and diseases. The larger the system, the smaller the allowance for improper control needs to be, as compensating factors such as improved management, and staggered planting normally occur which tends to provide better labour utilisation, better maintenance and general overall higher farming standards. Deep percolation losses are minimised with sprinkler irrigation unless water is applied very unevenly giving rise to areas of over-watering, or the irrigation system itself is over-capacity. Both these situations are normally avoided in well managed and designed systems and it is rare for a sprinkler irrigation project to require a drainage system unless the area has a naturally occurring drainage problem. In the State of Utah, *USA*, the high water tabel caused by the use of flood irrigation in the past has fallen considerably since sprinkler irrigation was introduced[5].

Uniformity of application

The co-efficient of uniformity is an important matter which will affect equipment selection and capital costs. In hand move and solid set equipment the uniformity is determined by the selection and spacing of the sprinklers and with the mechanical move equipment by the spacing of nozzles and the rate and distance of moves. Operating pressures are also important as they effect the break-up pattern of the jet and together with jet angle the wetted diameter. A number of measures of uniformity exist and the most important ones have been examined by Dabbous[6] who showed that they are either related mathematically or have a very close affinity to each other. The most widely used one is the coefficient of uniformity (Cu) proposed by Christianson[7].

The Christianson coefficient of uniformity is expressed as:

$$Cu = 100\frac{1 - \Sigma d}{mn}$$

where d = deviation of individual observations from the mean
m = mean of observations
n = number of observations

A Cu of 100 represents perfect evenness and lesser figures indicate decreasing levels of uniformity. This Christianson concept of uniformity although the most often measured, is subject to criticism because the figures produced from test results tend to be treated as percentages. High Cu's can be produced even though great variations in the depth of application can occur between individual readings. Sometimes these variations exceed 200% or more within the same wetted area and yet produce a reasonable Cu figure. The test results are calculated from the overlap patterns of several sprinklers and the percentage overlap has an important effect upon Cu.

As the Christianson formula for Cu is dependant upon the absolute difference between individual readings and the mean depth of application it can be expected that it has some relationship with the statistical concept of the standard deviation. The formal mathematical connection between them was produced by Hart and Reynolds[8] and their work has greatly improved the understanding and use of the Cu in the design of sprinkler systems. Although this initial work was based upon the assumption that the distribution pattern of water application from sprinklers was statistically normal, it has since been shown that where Cu's of 70 and above are recorded skewness of pattern does not invalidate the form of analysis as inaccuracies are very small and become negligible at high Cu's[9].

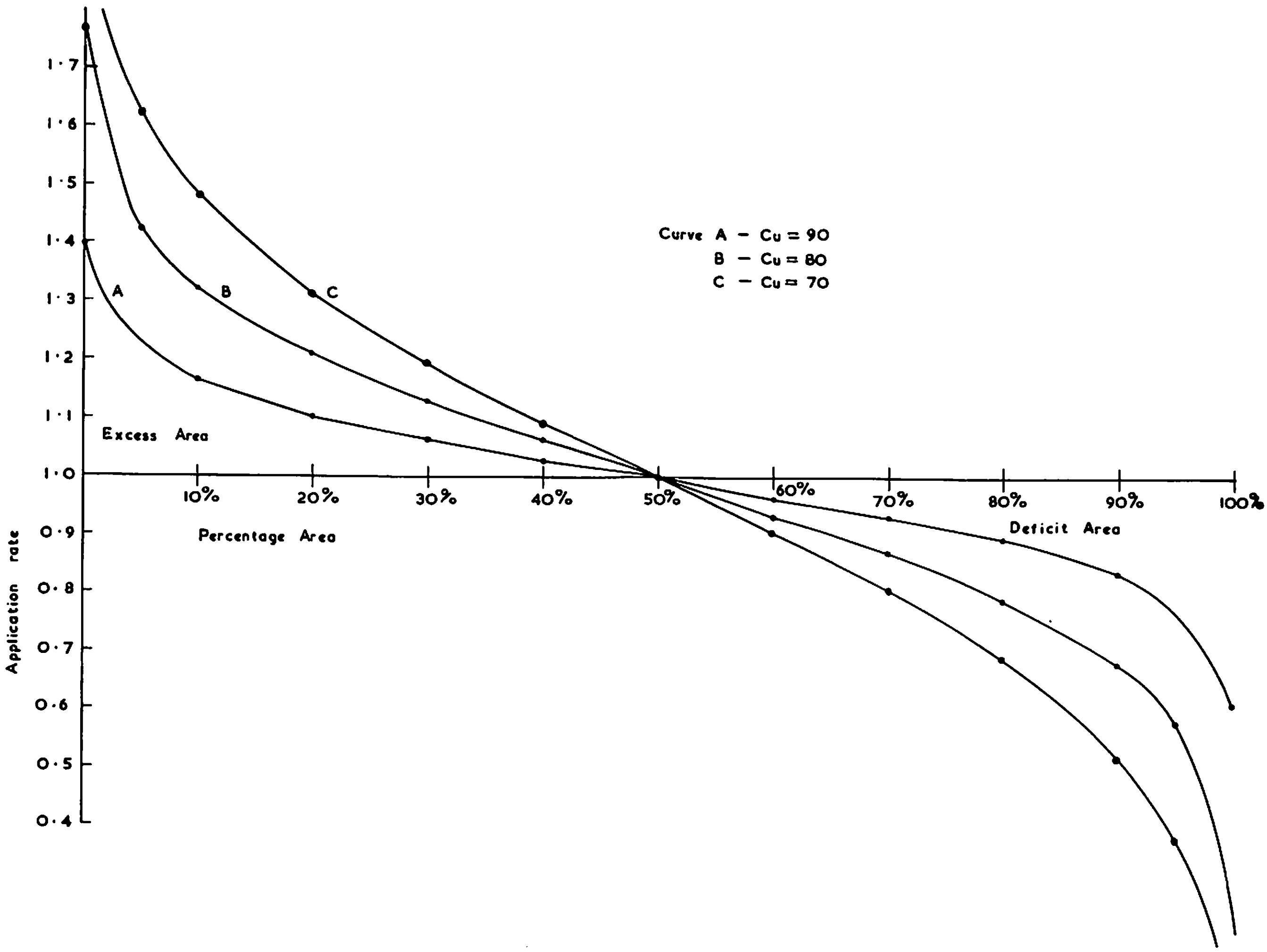


Fig 1 Application distribution at various Cu's within overlapped sprinkler pattern assuming mean application is 1.

Fig 2 Increase in system capacity required by sprinkler system to change adequacy from 50% to 80%.

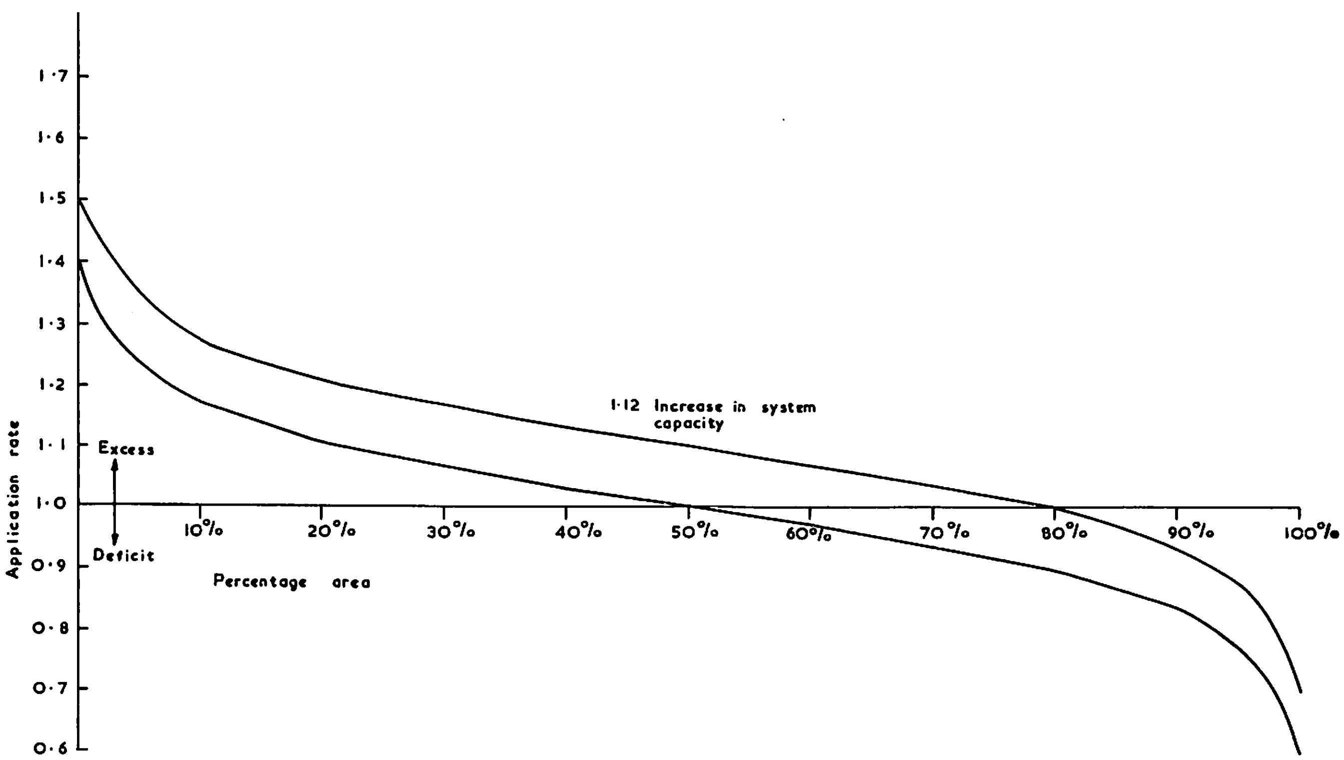


Table 1 Percentage areas adequately irrigated

Cu	95%	90%	85%	80%	75%	70%	65%
95	1.115	1.086	1.070	1.055	1.044	1.034	1.025
90	1.259	1.192	1.149	1.119	1.093	1.071	1.050
85	1.642	1.318	1.242	1.188	1.145	1.109	1.078
80	1.792	1.473	1.351	1.267	1.203	1.151	1.107
75	2.063	1.672	1.481	1.310	1.268	1.197	1.137
70	2.625	1.930	1.639	1.464	1.339	1.247	1.170
65	3.591	2.286	1.832	1.586	1.418	1.230	1.203
60		2.801	2.079	1.730	1.510	1.357	1.239

Increases in the net system capacity at various Cu's and adequacies of irrigation.

Table 1 and fig 1 demonstrate the connection between application rate and the areas adequately irrigated at various Cu's. If the mean rate of application is used, then by definition and from fig 2 it will be seen that at all Cu's only half of the wetted area will receive sufficient water, the remaining half being in deficit. The amount of deficit being proportional to the area enclosed by the relevant half of the Cu curve and the x–x axis. By similar reasoning the other half of the area will provide an equal amount of excess application.

In order to increase the area adequately irrigated the mean application rate has to be increased as demonstrated in fig 2. This indicates that some assessment must be made of the deficit areas and what adequacy of irrigation is required to produce the required crop. The reduction in crop yield produced by the deficit area may provide an economically acceptable crop or be significant compared to the cost of either increasing the area adequately irrigated or using sprinkler irrigation equipment with a higher Cu or both.

When it is required to increase the level of adequacy of irrigation it becomes necessary to increase the mean rate of application by some margin and as consequence the capacity of the irrigation system must be likewise increased. Associated with the increase in capacity of the system will be increased costs for pumping equipment, pipelines and operating costs which must be matched by an increase in crop yield. Table 1 gives the factors by which system capacity must be increased for various levels of adequacy of irrigation and Cu from which it will be seen that the increase in the mean rate of application for a given adequacy rises disproportionately with falling Cu.

The level of adequacy and Cu adopted in a rationally engineered system would be determined from a consideration of crop response to water; the capital and operation costs of the equipment. However, other factors are at work which tend to complicate the situation and make analysis difficult. Where low Cu's are used and the system capacity is increased to allow for this, the excess water applied in the areas receiving a higher application may provide a problem both from the point of view of drainage and the leaching of plant nutrients especially nitrogen.

For a given sprinkler working at its optimum operating pressure and flow rate, the Cu will depend principally upon sprinkler spacing. As Cu's generally, although not invariably improve with smaller spacings, there are increased capital costs associated with higher Cu's. The increased cost following the greater concentration of field equipment necessary to provide closer spacing. Commensurate with the increase in the intensity of equipment use will be an increase in labour costs.

The evenness of application of booms and centre pivots has not been exhaustively studied. The number of sprinklers dispersed along such equipment can be increased relatively inexpensively and the rate of movement forward arranged as circumstances demand. To some extent, therefore, the uniformity of application can be controlled by the operator provided he understands the principles involved and has a sufficient training to use this flexibility in an advantageous manner.

Evenness of distribution and adequacy are usually included in the efficiency figure used to calculate the gross irrigation requirement and are not declared separately.

Uniformity and wind

It has been assumed so far that the Cu remains constant during the whole of the irrigation season. In reality conditions are not static and winds plus the constant movement of the equipment means that variations in Cu occur at each irrigation season. Wind velocities up to about six miles per hour improve the Cu but winds beyond this speed cause uniformity to deteriorate[10]. The correct orientation of the equipment to the prevailing wind direction can assist, but as shown by Seginer[11] it is the vectorial difference in wind directions during sprinkling that is more important in some cases. Diurnal changes in wind speed and direction also complicate the determination of an acceptable Cu especially if the equipment operates in different positions at day and night.

The adverse effect of wind on uniformity can be overcome to some extent by the use of the alternate move system. Under this system of operation during alternate irrigation cycles sprinkler lines are stationed in an offset position half-way between those occupied in the previous irrigation cycle. As some crops in the area may have been stressed during the first cycle they now receive ample water and the excess is stored in the soil profile to allow for the lesser amount they will receive during the next cycle. The efficacy of the system of operation depends upon the presence of a soil sufficient water storage capacity within the root zone of the plant. During the first stress period the roots of the crop may be encouraged to enlarge and thus automatically provide a larger root zone and hence some additional safeguard.

Solid set systems cannot by definition be operated in this manner and a sufficiently high Cu must prevail under the majority of wind and other situations. The mechanically moved equipment can easily conform to the alternate method of movement, but in the case of the pivot move this is not necessary as it usually moves forward slowly automatically. However, boom and centre pivot systems can be affected by winds at their extremities if the nozzle is made to fire water a long way to give additional irrigation coverage. In the case of booms, an overlap of the outer edges of the wetted diameter can be arranged, but with centre pivot no such overlap can be readily arranged and the corners remain dry, a large circular area only receiving water.

It has been found that even without the alternate method of operation the accumulation of irrigations at the same place over an irrigation season improves the seasonal uniformity[12]. Also the longer the operating period at any one time, the higher the Cu is likely to be on any single occasion. The range of Cu's used in any analysis work are most likely to be those occurring under average field conditions. Cu's measured in still air conditions are helpful as they confirm that products are conforming to manufacturing standards, but it is necessary for such results to be modified to correlate more closely with field conditions.

Uniformity of distribution along a sprinkler line

Due to frictional losses the pressure along a sprinkler line will fall. The rate of frictional loss decreasing as the flow diminishes as successive sprinkler points are passed. The rate of decrease of frictional loss falls rapidly after about the first third of the sprinkler line because losses are proportional to q^n, the exponent n normally being of the order of two. In order to keep the output of each sprinkler within acceptable limits Christianson[7] proposed that the frictional losses along the sprinkler line should never exceed 20% of the operational pressure of the first sprinkler. Adopting this criteria means that the first sprinkler passes about three percent more than the calculated mean. The 20% variation in operating head between the first and last sprinkler includes differences in elevation between the two so that this quantity of head is not always available for balancing against frictional losses. The other part of the package proposed by Christianson under the 20% rule was that the pressure at the beginning of the sprinkler line should be raised to the operating pressure of the mean sprinkler plus three-quarters of the difference in head between the first and last sprinklers. These rules of thumb have never been seriously questioned and are quoted in most of the sprinkler irrigation design manuals.

The adoption of these design criteria means that the total flow of the sprinkler line is raised by approximately two–three percent above that which would prevail if each sprinkler was made to pass the mean flow rate. As it is, each sprinkler passes a slightly different quantity of water and if the reasonable assumption is made that each sprinkler in spite of having a different flow achieves the same Cu then the adequacy of irrigation along the line is represented by a number of curves very close to each other. Each sprinkler down the line irrigates a little less adequately than its upstream neighbour. Under the stated Christianson design criteria, the first sprinklers along the line achieve a higher adequacy of irrigation than planned and those at the end less. The flow of each sprinkler could be obtained and a crop response calculation made. The crop output for the complete line could be calculated by summating the results from all sprinklers. A number of different sprinkler line design criteria could then be examined in return and a choice made on a rational economic basis.

As indicated earlier precise water production function curves do not exist and until this data is made available the method of analysis suggested cannot be undertaken. However, it should be noted that the 20%, three-quarters pressure rules may not be valid for all cases, and in fact where irregular farms are involved it is suggested that for some crops it is acceptable to have frictional losses amounting to 30%. If high value crops are to be irrigated it may be that variations of pressure of only 15% are justified.

It is theoretically possible to have each sprinkler fitted with a different size nozzle to ensure that they all pass the same quantity of water. This would mean that for hand move equipment the field operators would always have to lay out the sprinklers in a special sequence on every occasion. Such a task is clearly too onerous.

In case of the mechanical move equipment different size nozzles can be fitted along the line, which is the normal practice. The equipment is such that the wrong positioning of a nozzle is hardly likely.

Capital costs, uniformity and rainfall probability

The adequacy of irrigation and the coefficient of uniformity have so far been considered without including the modifying effect of rainfall. In the arid tropics this is not necessary but where irrigation is carried out to supplement rainfall then there is a distinct likelihood that the level of adequacy and the acceptability of particular Cu's will be changed. In Europe, Canada and the North Eastern *USA* sprinkler irrigation is carried out where much rainfall can be expected during the crop growing period. In the sub-humid tropics, definite rainy seasons are discernible and where these periods of rain are artificially extended by the use of irrigation, such as for coffee in Kenya, then it is possible to modify the system design accordingly.

Under these conditions it is necessary to have rainfall records over a sufficiently long enough period to enable probability levels to be calculated. Once the quantity of rainfall in a given period and its probability is determined, then the adequacy set against any particular Cu can be modified accordingly. It has been found by Levine and Seginer[13] that in humid areas acceptable Cu's can be considerably lowered. If lower Cu's are acceptable in any given situation then this has a distinct effect upon capital costs and ultimately the operating costs of the system. These cost reductions come about because sprinklers can be used at wider intervals than in arid conditions which ultimately leads to the use of less field equipment.

Uniformity and adequacy

The two factors of uniformity and adequacy of irrigation can either separately or together affect capital and operating costs as already argued. If the crop response curve to water is known then it will be possible to summate the crop output in the adequately and inadequately irrigated regions of the system. From such information it would then be possible to select a system which provides the optimum economic choice. A range of equipment annual operating costs for various acceptable mixes of Cu and adequacy could be computed and the value of the crop output measured. The maximum difference between increased crop revenue and cost being the best solution. This method of attack whilst exact suffers from the disadvantage that it is difficult to obtain the necessary information on crop response to water. Where water is in short supply the advantages of such a method are obvious as it will provide the most beneficial use of a scarce resource. Other inputs such as nitrogen fertiliser may provide a substitionary effect for water as shown in fig 3. It is reported[14] that fertiliser treatment, climate and other factors tend to be additive in a given location when considered on a yearly basis. However, it is apparent that the input of fertiliser can disproportionately enhance the use of water. Thus before a precise uniformity and adequacy of irrigation can be selected it is necessary to know more about the combined effects of all the inputs in a given farming situation. One attempt to provide such information for the North Dakota area of the United States is currently under review[15].

The result of water-plant response curves measured in other locations could be used, but specialists in agriculture caution against the dangers in using such data even if it is recorded in areas with similar crops, soils, climate and farming conditions. Many variables exist which could invalidate the results[16].

Once sufficient data is made available for any given situation a computer analysis using linear programming or a similar technique will be the only present method by which every combination of factors could be considered in order to provide the optimum solution. Concurrent with the exactness of such an analysis it will be necessary to provide a management structure which can adequately

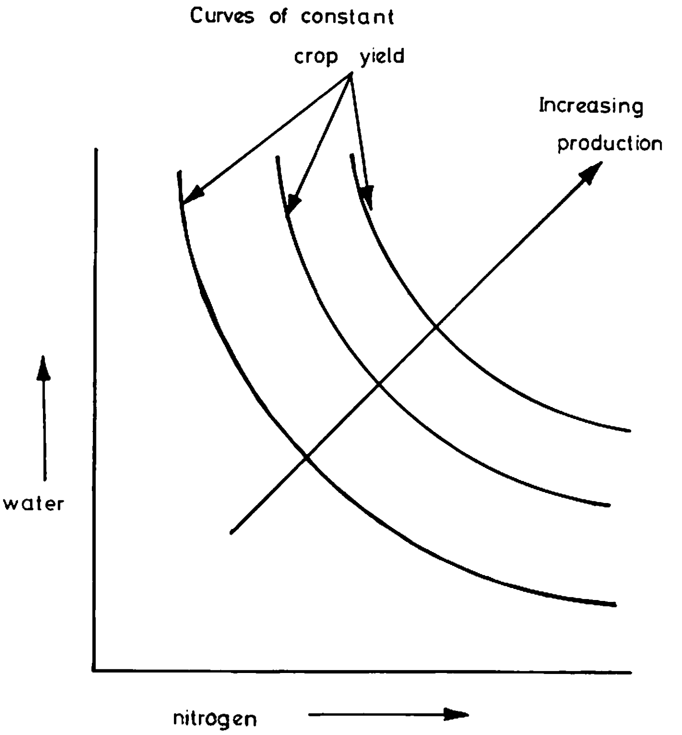


Fig 3 Indifference curves; crop response to the combined use of water and nitrogen.

enforce the selected programme of operations. Such levels of supervision are largely absent in under-developed countries and even in countries where farming technology is advanced it is also highly unlikely that the present skills of management are suitable for such precise farming regimes. As resources become scarcer and more expensive it is probable that such methods of analysis will become necessary and ways found to implement the optimum choice.

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Research and Development Work at Wye College (University of London)

WYE COLLEGE situated in the south-east of England and the establishment of its Centre for European Agricultural Studies emphasising its proximity to Europe has a considerable interest in new arable crops such as maize which are important to the European farmer. The College already provides an obligatory course in Farm Mechanisation in the final year of the *BSc* Honours degree course in Agriculture. Students can also submit a special study which can be on an aspect of farm engineering as an option in degree courses in Agriculture and Horticulture. Facilities are also available for research programmes leading to *MPhil* and *PhD* degrees requiring periods of study of not less than two and three years respectively. Arrangements can sometimes be made for staff of approved bodies and research institutes both in this country and overseas to register for higher degrees.

Research and development work in agricultural engineering and farm mechanisation is currently based on three major topics covering the research interests of the academic staff in co-operation with other related departments and the Wye College Maize Unit.

Cultivation

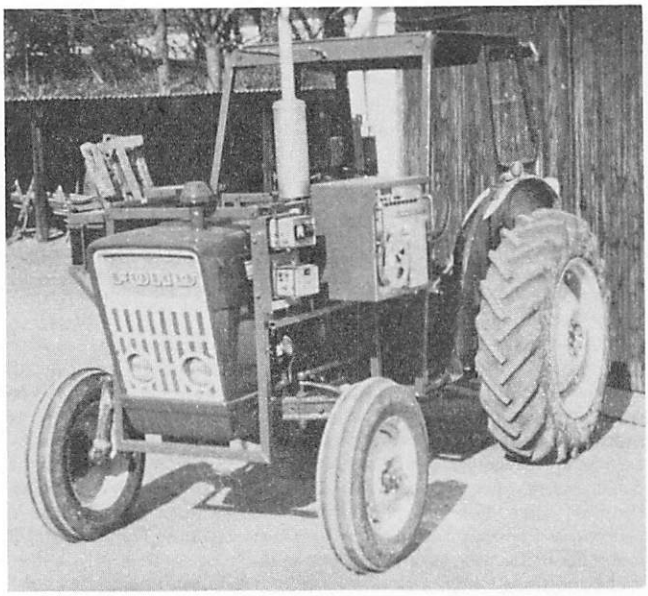
Work is in progress on drilling methods and on the effects of spacing on ease of harvesting of maize. Development work is also envisaged on alternative cultivation systems for this crop. Environmental studies of the effect of soil treatments such as ridging, mulching etc on soil temperature and growth of maize are also being conducted. An experimental double digger is currently being developed in a joint project with the Soil Science Department, which will thoroughly pulverise the sub-soil since preliminary work has shown this to improve crop growth and yield of barley and ryegrass.

Crop harvesting

Optimum machine systems for harvesting and drying of maize are being developed with the aid of a simulation model. This requires original data on lodging, harvesting losses and length of harvesting season. Some of this data will be obtained from field experiments which are in progress. This programme also includes the evaluation of alternative drying systems for maize using a mobile recirculation batch drier funded by the Home-Grown Cereals Authority.

A low cost maize attachment for the standard cereals combine harvester was developed at Wye in 1969. Performance of this attachment is being assessed in conjunction with *ADAS* with five

A combine harvester fitted with the 'Wye Header'.



Instrumentation for measurement of tractor performance in the field.

headers distributed to different sites in the grain maize growing area during 1973. At each site, performance is being assessed relative either to a standard maize combine harvester, or an unmodified cereals combine. Studies are also being made on the combine harvesting of Navy beans, another important new cash crop to Europe. The main problems are the proximity of the pods to the ground, the effect of harvest moisture content on damage at threshing and the staining of the beans by weeds during threshing. On the other side of the country, work sponsored by *BP* International Ltd, on the use of chemical additives on baled moist hay is being conducted at the University College of Wales, Aberystwyth. The dry matter and chemical losses of rye-grass and Timothy hays in the bale have been measured and have been shown to be dependent on moisture content and temperature. The current problem is the distribution of the additives within the bale, which is being investigated with the aid of a fluorescent tracer.

Tractor performance

Work has been completed on the development of instrumentation for the measurement of tractor engine load in the field. This depends on precise measurement of the fuel consumed each second by the tractor in work. Comparisons of power measurement by new instrumentation and by a dynamometer have shown close agreement within ±3 hp. The instrumentation is easily transferred from one tractor to another; it is powered by tractor batteries and the data is recorded on punched paper tape in a form suitable for computer analysis. The wide range of possible applications for this instrumentation includes the testing and development of new machinery, the matching of tractor and implement size, the assessment of field efficiency of machinery and the investigation of drivers' ability.

For the future an increasing emphasis of the research and development programme is envisaged on processing food crops such as legumes and brassicas, particularly the harvesting and packaging aspects.

I. B. Warboys

The Institution's Move to Silsoe

AS members are already aware, one of the recommendations of the Council Working Party, aimed at streamlining the administrative work of the Institution, was that the Secretariat should move from the premises at Rickmansworth, which the Institution has occupied since 1965, to a more appropriate location.

Following acceptance of this proposal by Council and by the Annual General Meeting on 3 July 1973 arrangements have now been finalised for the Secretariat to move to accommodation at the National College of Agricultural Engineering, Silsoe, with effect from 1 January 1974. In the first instance, the Institution's offices will be established on the ground floor of what was formerly the Principal's house at the College. It is hoped to provide permanent accommodation at Silsoe in due course, probably on a site to be leased from the College. Plans both for the construction and financing of a new building are now under discussion and will be announced as soon as possible.

Access to the offices can be obtained through the main entrance to the College, but a more direct route is via West End Road, Silsoe, as shown on the plan below. **The postal address will be, The Secretary, Institution of Agricultural Engineers, West End Road, Silsoe, Bedfordshire. MK45 4DU.**

The temporary accommodation at the *NCAE* will provide a secretary's office large enough to serve also for meetings of small committees or working groups, a clerical office, a store/duplicating room and toilet facilities. Ample car parking space is close at hand.

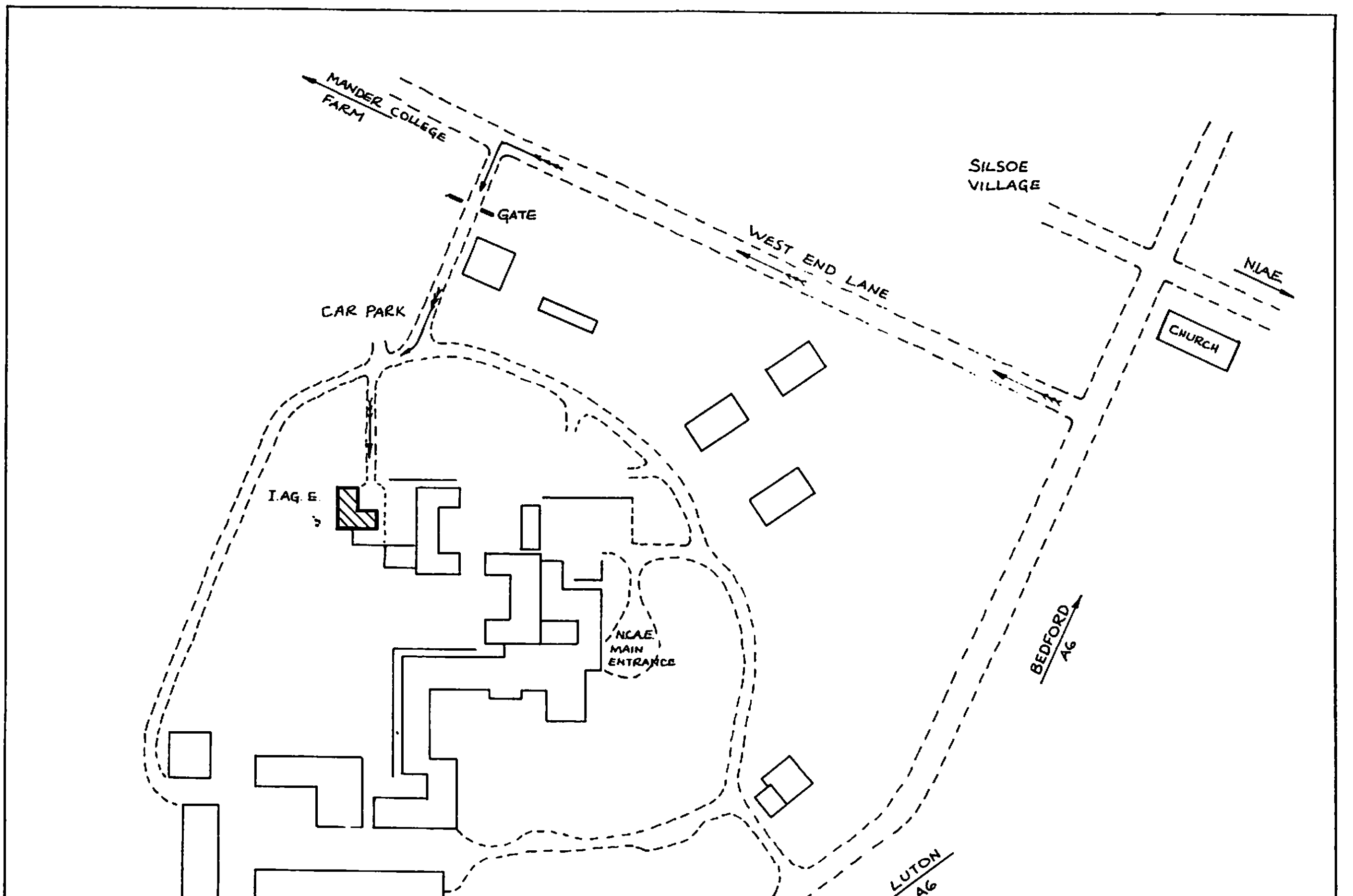
The Silsoe office will initially be manned by Mr Ray Fryett AIAgrE, working on a part-time basis as a special assistant in the Secretariat, plus one or two members of clerical staff, to be recruited as the work at Silsoe develops. For domestic reasons, the clerical staff at Rickmansworth is unable to move to Silsoe.

Mr H. Weavers will continue as Institution Secretary until his retirement in June 1974, working mainly from his home at Bushey, Herts. As already announced, the full-time post of Secretary is being advertised and a selection committee under Mr John Fox, President-Elect, has been set up.

The move to Silsoe marks the second major stage in the redevelopment of the Institution's Secretariat and administration. The new headquarters at Silsoe, close by the *NIAE* and actually on the *NCAE* campus, will be situated at what is now indubitably the centre of agricultural engineering in Britain. There is, however, no intention to seek charity or special consideration from either of the national bodies at Silsoe, or to presume unduly on the time and goodwill of members in the Silsoe area. Indeed, there is expected to be a considerable saving of time for those members of Council and other committees who work at Silsoe, since some of the activities previously carried out in London will now take place at Silsoe. It is likely that meetings of Council and of the Executive Committee will continue to be held in London in the normal course of events, and every effort will be made to ensure that members outside the Silsoe area are not inconvenienced through the change of location.

In my view the move is a very important step in re-shaping the Institution to meet the demands of the future, and that it is right both in physical and in psychological terms for it to join the other major agricultural engineering bodies at Silsoe, and I look forward with eager anticipation to the opportunities that await the Institution in 1974.

J. A. C. Gibb



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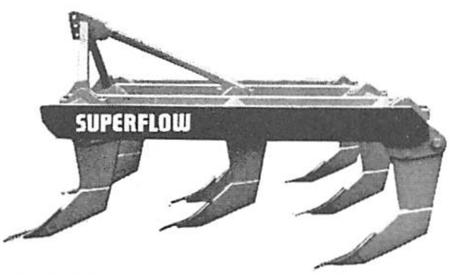

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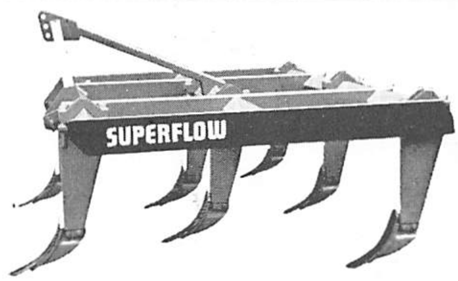

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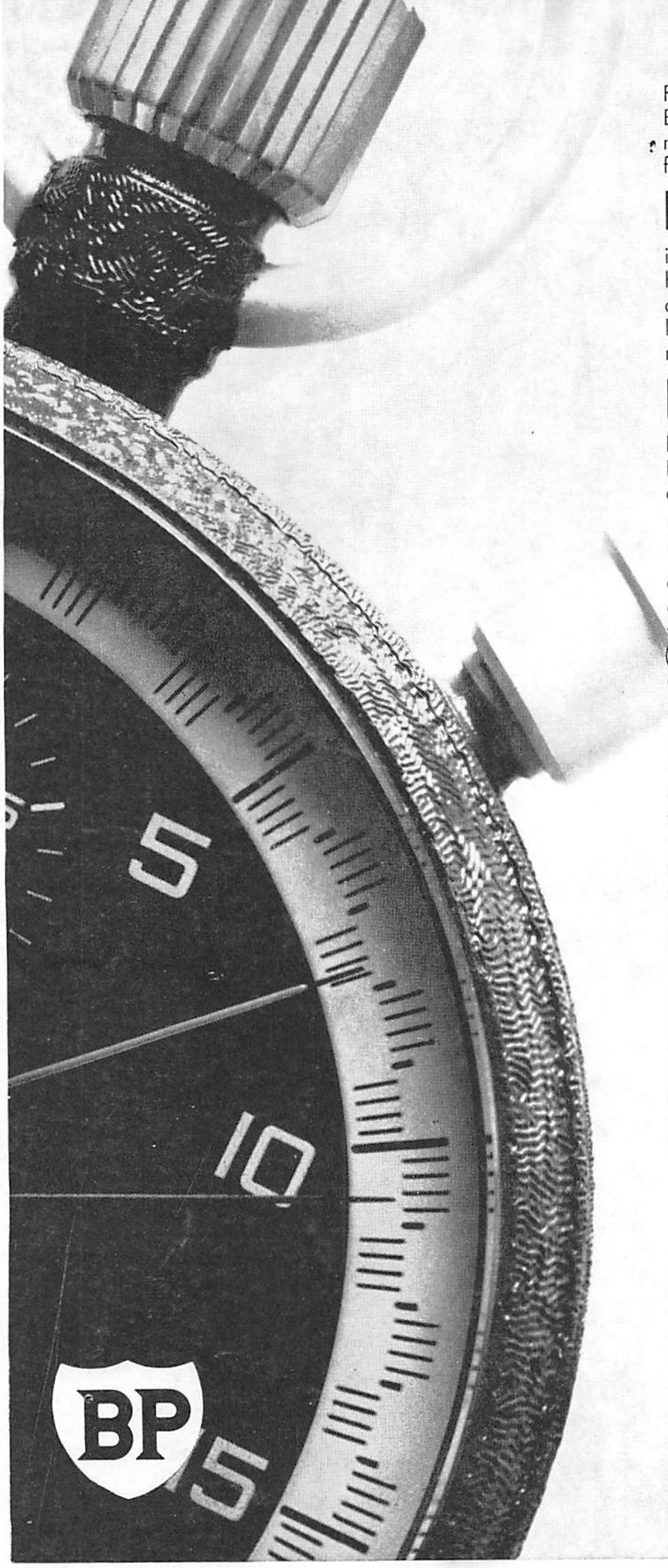


Few farm people have time to waste. Especially on lubrication. BP now save you time and trouble with a newly-formulated multi-purpose farm oil. New BP Super TOU covers all these farm requirements...

For all farm engines

including tractor engines with a Series 3 requirement. New, high performance engines need an oil which minimises carbon deposits. BP Super TOU, based on new lubricants technology, keeps pistons clean. Wear is reduced and power output maintained.

For oil-immersed disc brakes

No more need to worry about special wet brake additives. New BP Super TOU lubricates wet brake transmissions and contains a friction modifier to alleviate squawk.

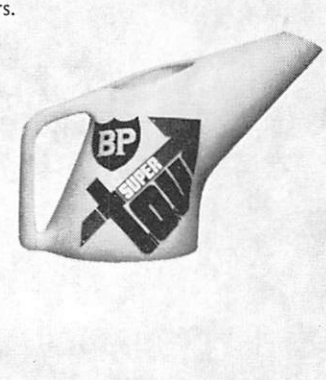
For transmissions

on tractors, combines, planters, harvesters, balers, conveyors, elevators, etc. New BP Super TOU is a high load-carrying oil which offers maximum resistance to wear.
(Exceptions: IH and John Deere tractor transmissions; all semi-automatic transmissions; Land Rover axles; some other machinery. See BP Farm Lubricants User's Guide.)

For hydraulics

Use new BP Super TOU for hydraulic systems combined with tractor transmissions and others, including combines. This new oil keeps hydraulics efficient and responsive. It also fights corrosion–especially important on machines in store such as combines. Rust-vulnerable components such as servo valves and control mechanisms are effectively protected by new BP Super TOU.

New BP Super TOU saves you time by simplifying lubrication. And keeps down machine down-time because it more than meets the protection demands of modern, high performance farm machines. If you have a mixed fleet including modern machines, you must have new BP Super TOU. For older machines, regular BP TOU is still available. Contact your BP Farm Service distributor or your agricultural traders.



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