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Irrigation Practices: Peasant-Farming Settlement Schemes and Traditional Cultures [and Discussion]

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Irrigation practices: peasant-farming settlement schemes and traditional cultures

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Science has been highly successful in soil conditioning, plant breeding, and in pest and disease control, but has not yet turned its full attention to making the best use of water for irrigation. As water becomes scarcer worldwide so the need for more efficient water use becomes a necessity for peasant agriculture. It is to this theme that this paper principally addresses itself.

In SE Asia flooded rice irrigation occupies some 70 Mha and is expanding at such a rate that water is becoming increasingly expensive to provide. In these circumstances there is a need to look critically at the methods of irrigating and growing rice. The practice of transplanting seedlings and whether rice could be grown equally as successfully in non-flooded conditions requires investigation. The way ahead is being provided by the economies forced on farmers who pump water from their own boreholes.

Although the Dumoga project in north Sulawesi, Indonesia, has not yet reached the point of farm development where water shortage is a problem, that time will come; and the scientific programme that is already underway in the area (under the auspices of the 'Project Wallace' expedition) could usefully be expanded to include the technical and sociological problems involved in water allocation. Similar studies would also benefit hill irrigation in Nepal, Peru, the Philippines and similar mountainous areas. Excessive soil saturation and poor water control are frequent causes of catastrophic landslides and soil loss from erosion.

In those arid zones with a tradition of irrigation and access to oil revenues, better water control can be achieved by the introduction of combined manual and electronic control systems. In Iraq, for example, these systems will help to make the best use of the restricted waters of the Euphrates basin. Scientific advance in irrigation methods is more difficult to foresee in the arid sub-Saharan areas, where the adoption of techniques already successfully applied elsewhere is likely to be the prime necessity.

1. INTRODUCTION

A worldwide review of irrigation practices as they relate to peasant-farming settlement schemes and traditional cultures is too broad an undertaking to be of lasting interest unless it can concentrate on those aspects where science has a definite role to play. Thus instead of describing the varying state of such schemes around the world and attempting to make philosophical points on the nature of their investment and managerial shortcomings, and the need for more farmer participation in running their own schemes, this paper concentrates on irrigation practices to which science has not yet given full attention, namely the control of water and the economy of its use. This aspect is of particular interest to peasant schemes owing to the small size of holdings (and hence the multiplicity of farmers) and the lack of control over water use exercised by price; that is to say, by not being easily able to charge for water as is the normal practice on capital-intensive irrigation schemes in the developed parts of the world.

One particular example will illustrate the relation between the control of water and the willingness to pay for its provision. A recent World Bank Project completion report for an irrigation investment in the Far East states (World Bank 1984):

> 'Several aspects must be considered in deciding how the burden of main system operation and maintenance costs should be shared.† Besides calculating the farmers' ability to pay we should also assess their willingness to pay. The latter is eventually a political problem which may be eased if main system water supply can be assured. For example, farmers are willing to pay high pump charges (from schemes exploiting groundwater) since they recognize the very high returns obtainable from flexible and manipulative water resources,... It has been suggested that if water user associations had a closer tie to provincial public water departments, and farmers could feel they were able to influence the quality of service, willingness to pay would increase.'

In adopting this theme of water control it is not to be construed that water has a pre-eminent position, and it must be stated from the outset that the author fully recognizes that the desired end is not the application of water in itself, but that irrigation is simply one of the means to improve crop production and to the increased well-being of the farmers.

The fact is that science has already been highly successful in soil conditioning, plant breeding, and in pest and disease control but has not yet turned its full attention to making the best use of water. The assessment of what is required in water control has been more by trial and error than by process of scientific research.

It should also not be construed that science and technology as a whole have a pre-eminent position in irrigation development. Less the role of further scientific and technological advance takes on too great a significance, it needs to be emphasized that many peasant schemes do not achieve the predicted crop yields and predicted total production for either or both of two reasons. First, the failure of managers at farm, scheme, and governmental level to run their concerns to the best advantage (generally owing to poor financial incentives); and secondly, the failure of designers to take properly into account soil, topographic, water, and human limitations. Thus it must be conceded that great advances can be made by removing the causes of management and design failures and that the introduction of further science and technology may not be a first priority.

Nevertheless, even in situations of poor management, the introduction of advanced techniques (in automatic control of water for instance) may well be able to simplify the tasks of management and make success more probable.

2. Definition of peasant schemes

A narrow definition of a peasant scheme is that it is operated by subsistence farmers, but because subsistence farming entails a cash-less economy and the whole object of irrigation development is to improve a farmer's lot, such a definition hardly leads to scientific advance. Thus the definition adopted for the purpose of this paper and which does not trespass too seriously on the capital-intensive approach of Mr G. R. Hoffman (this symposium) is as follows. 'Peasant-farming schemes are those schemes where capital for development has its origin with

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† There is no suggestion that the farmer should pay for any of the capital cost.

central government (perhaps with the assistance of international aid agencies) and where it is unlikely that the government will ask farmers to pay back their share of the capital costs directly. Indirect payment by means of a land or produce tax may be levied, to add to government revenues, but no attempt is made to recoup the whole capital cost.' No doubt there are exceptions to this definition, but whatever wording is adopted, today's peasant is tomorrow's capitalist as is witnessed by the replacement of the hoe with the buffalo and the buffalo with the tractor, and some overlapping into the 'capital-intensive' field cannot and should not be avoided.

With this definition as a basis and with the need to put peasant irrigation into a world context, the best way forward seems to be to deal with irrigation in selected climatic zones, using, where appropriate, examples from specific projects and mentioning the role that science and technology has played and what still needs to be done.

3. Peasant irrigation in the humid tropics

According to the above definition, peasant irrigation schemes comprise approximately 75% of the 250 Mha irrigated throughout the world. At least 70 Mha of this area are used to cultivate flooded rice in SE Asia. Thus it seems appropriate to begin with a discussion of peasant irrigation in the humid tropics, where rice irrigation is the principal activity of most of the people and takes place on the most fertile land.

Flooded rice irrigation is the familiar picture of terraced plains and hillsides fed by a network of canals supplied by a river diversion structure or occasionally by a storage dam. The unique feature that distinguishes flooded rice schemes from others is the need for level growing surfaces and the facility to transfer water from terrace to terrace. In recent years groundwater-fed rice schemes have been in vogue, but the cost of providing water and the difficulties of finding the necessary high-yielding aquifers, have meant that the areas so irrigated are insignificant in terms of total crop production, although they can (with the aid of subsidies) benefit the farmers directly concerned. Nevertheless, groundwater-fed rice schemes force designers and operators to think twice before being wasteful of water. Expensive diesel fuel or electric power is effectively poured into a borehole to get water out and the need to economize on water use becomes much more apparent than it does on 'run of the river' abstraction schemes or even on Malaysian-style schemes pumping directly from the river. In the latter, energy inputs are relatively low and farmers have come to expect fuel to be provided cheaply by the government. So experience in designing groundwater schemes (Wild 1984) is acting as a catalyst to make designers look at the efficiency of water use on irrigation systems generally and to see whether production could be increased by applying similar principles.

(*a*) *Economy of water use*

As irrigation development proceeds (in Indonesia alone the target is 1.9 Mha of new development, rehabilitation, swamp reclamation, and flood control during the fourth five-year plan from 1984–5 to 1988–9), so water becomes scarcer, or more expensive if drawn from storage dams, and economy of use becomes essential. Even on existing schemes the full production potential is not being realized owing to excessive use of water by those closest to the source and shortages on the more remote farms. The traditional American homesteaders expression for this situation is that an 'upperority' is better than a 'priority'.

A surprising fact is how little attention designers give to 'efficiency water' and to the water that percolates below the root zone of the crop. Rice water requirements are the sum of crop consumptive use (actual crop evapotranspiration in other words) and percolation less effective rainfall plus an allowance for wastage owing to poor management. Because of the difficulty of assessing what this wastage might be it is usually taken care of by dividing the better known factors by an efficiency, as shown in figure 1.

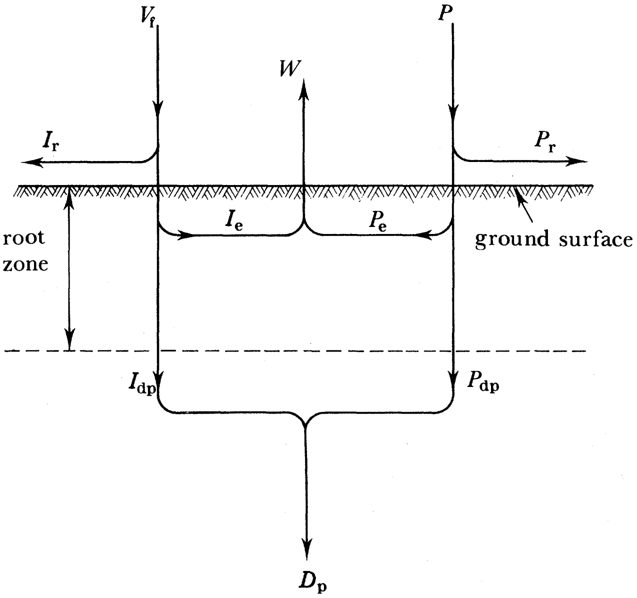

FIGURE 1. Soil-surface and root-zone irrigation water inflow–outflow diagram.

$$Vf = W - P_e + I_{dp} + I_r$$
$$= (W + I_{dp}) - P_e + I_r$$
$$= [(W + I_{dp}) - P_e/E_a,$$

where V_f = farm irrigation supply; W = crop evapotranspiration; P = precipitation; I_r = surface runoff from farm irrigation supply; I_e = effective irrigation supply; P_e = effective precipitation; I_{dp} = deep percolation from farm irrigation supply; P_{dp} = deep percolation from precipitation; D_p = total deep percolation; E_a = water application efficiency; P_r = surface runoff from rainfall.

Total irrigation water demands may reach 8 mm d^{-1} or more during the crop growth period, of which some 2.5 mm may be lost as a result of poor management and 2 mm by deep percolation. These 4–5 mm are not necessarily lost irretrievably because some may turn lowland into swamp, some may benefit lower users on the scheme itself, and some may benefit downstream schemes. When conducting river-basin studies it is normal practice to allow for such return flows, yet it is seldom in the humid tropics that water balances are investigated at project level. While it is inconceivable for a borehole owner to be prepared to lose more than 50 % of his water for someone else's benefit, those responsible for making the best use of storage dams adopt a casual approach to water-use efficiency and make very approximate estimates of return flows benefiting lower users.

Of course, if little or no water is reaching the sea then the river-basin efficiency might be said to be approaching 100 %, in which case local-scheme efficiency is of little interest except to individual farmers who might be suffering from inequality of distribution. This is very much the situation in drier climatic zones. In the Mataquito river basin in Chile for example, where farm efficiency is a low 50 % only 10 % of the catchment runoff reaches the sea; in other words the basin efficiency must be *ca.* 90 %. Nevertheless the state of water affairs in the humid tropics is that scheme designers generally ignore the re-usability of the 'efficiency' and deep-percolation water.

This problem of accounting for the efficiency and percolation water takes on a greater significance when it is asked whether the transplanting of rice is necessary at all in the humid tropics: can rice be 'direct-seeded', so saving water and disruption to the plant (Clark *et al.* 1982)? Even if transplanting is necessary for reasons of tradition, soil preparation, and weed control, can rotation of the water supply be introduced (especially during land preparation) instead of the continuous throughflow of water that is common at present? Can flooded ricefields be avoided entirely if plant breeders can find suitable varieties, and if weeds can be controlled to allow cultivation and irrigation like any other cereal?

(*b*) *Project Wallace*

These questions are relevant to any irrigated rice scheme in SE Asia. An example of such a scheme is the Dumoga project in north Sulawesi, Indonesia, whose location is shown on figure 2.

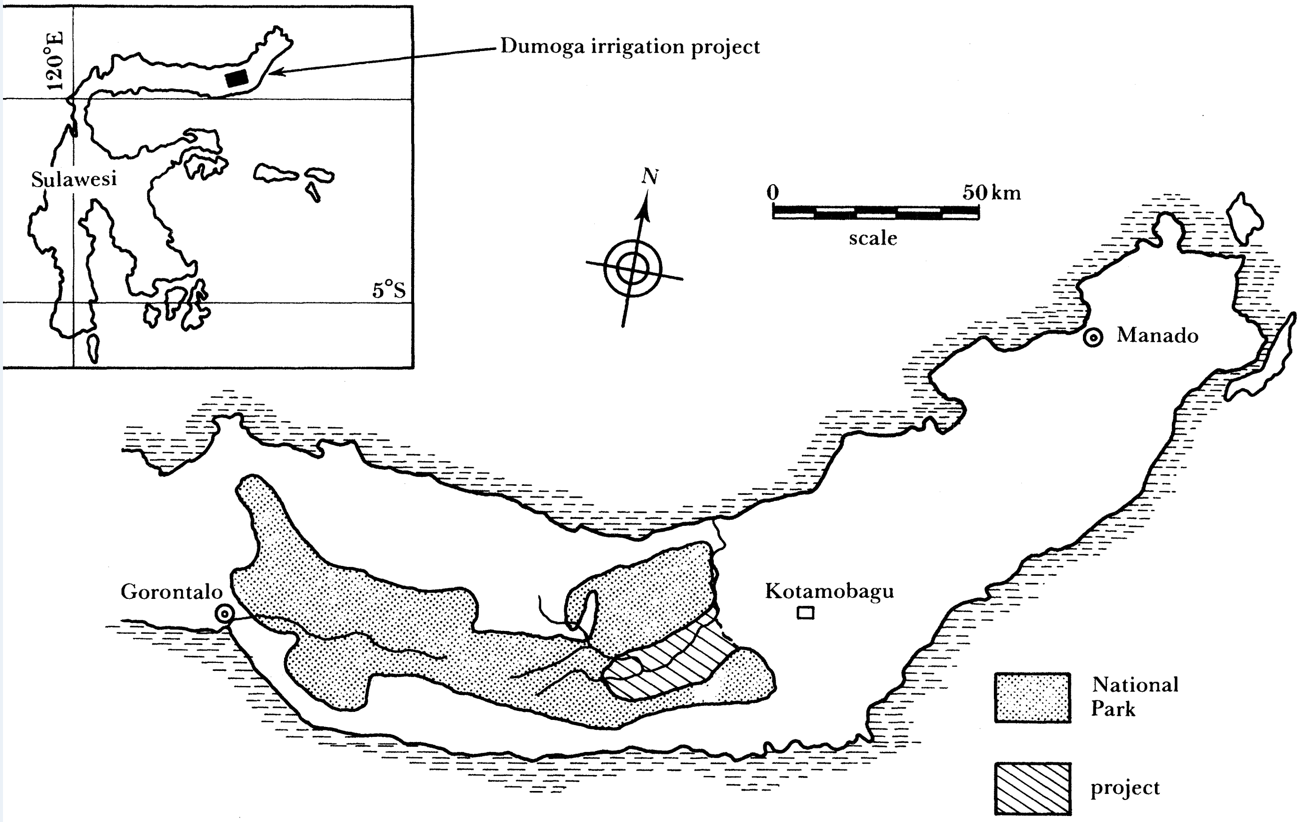

FIGURE 2. Location of Dumoga irrigation project and Dumoga Bone National Park, north Sulawesi, Indonesia.

The irrigation area totals some 7500 ha, of which approximately half has now been terraced for flooded rice irrigation. The main problems associated with the project have been protracted construction periods (thus upsetting the predicted economic returns), budgetary delays, and land tenure problems. These problems have meant that a project whose construction planning began in the 1960s only had its main and secondary canal infrastructure completed in 1981.

Of particular concern have been the land-tenure problems associated with the development of the area (Binnie *et al.* 1971). The few original inhabitants strongly resisted the influx of migrants that the scheme encouraged and who would be required when it was completed. Matters were brought to a head in 1963, when the governor of the province signed an agreement re-allocating 16 kha in the Dumoga valley as a transmigration area, where up to 6000 families could be resettled after the volcanic disaster resulting from the eruption of the 3142 m Gunung Agung in Bali. However, when *ca.* 600 families arrived from Bali they were unable to occupy their allocated areas, as once again the residents engaged in shifting cultivation demanded compensation for loss of any land they had ever cultivated. The disputes continued for another two years, until 1965, during which time the Balinese transmigrants (refugees), who lived in barracks, were unable to develop land for agriculture and plans to move in more families from Bali were abandoned. However, during the last decade all has been resolved amicably as far as the 600 Balinese families are concerned and these families now form the guiding light for rapid terrace construction and efficient rice irrigation. This land tenure difficulty illustrates the all-prevailing influence of non-scientific problems that beset irrigation development.

So far, water insufficiency problems have not been apparent in the project, even though water availability is marginal unless applied efficiently. The reason for this is that not all the irrigable land is yet occupied and farmers are able to use their traditional methods of continuous irrigation in which water is passed from flooded field to flooded field, and there is little scope for making the best use of rainfall because the padis are all full. This constitutes one of the problems that science can help to resolve, namely, what water saving would rotational irrigation provide and what extra land could be irrigated, and (more specifically), how much rainfall can be taken as effective if rotational irrigation is introduced?

The year 1985 sees the mounting of an expedition to commemorate 'the historical origins of the Royal Entomological Society and its early links with Indonesia through the work of Wallace'. The expedition's field of operations is the Dumoga–Bone National Park. The pressure to set up the Park was given impetus by the construction of the Dumoga irrigation project and the need to prevent settlement in the catchment area, forbid logging and to preserve the unique ecosystem. The credit for setting up the Park belongs to those engineers, conservationists and administrators (Indonesian, British, Dutch, and other nationals) who had the wisdom and perseverance to push the concept to its present state. It can be said that without the irrigation scheme there would have been no pressure to set up the Park, in which case land clearance in the catchment area would gradually have destroyed the forest and the water runoff pattern. Without the Park, the water supply to the irrigation scheme would be in jeopardy and the task of the scheme's managers in distributing equitably the changed pattern of runoff would have been more difficult.

The work of the expedition is not directly related to the control of water at scheme level but, through its 'forest regeneration' programme and other programmes aimed at preserving the ecosystem, its task is to help provide the necessary prior control in the catchment. The only programme directly concerned with the irrigation project is the 'agricultural entomology' programme, part of which will investigate the build-up of pests such as the brown planthopper which has caused large crop losses in recent years. It is perhaps unfortunate that there is no sociological programme to study the farmer's part in the operation of the scheme and in the related problems of water scheduling and control. Perhaps such an involvement can be included in a follow-up programme so that the need for the farmers to successfully run their farms and irrigation systems is recognized as an essential component of the whole ecosystem.

4. Application of SE Asian success elsewhere

Although there are many problems of water control to be overcome in the humid tropics in SE Asia, it is important to note that what can be achieved in that vibrant area of the world is more difficult to achieve in Africa and Latin America. The three factors for successful irrigation are all present in SE Asia. These are:

(i) A high population density and consequent pressure to develop all cultivable land.

(ii) The clear need for irrigation although rain-fed farming is possible.

(iii) The long cultural history, which means that the discipline required by irrigation is in-built into the communities.

It is the absence of these factors that made irrigation by smallholders on the 5000 ha Llanos de Coclé Project, Panama, and the 20000 ha Córdoba No. 2 Project, Columbia, or by villagers in the more humid areas of Tanzania, so unlikely to be successful.

One outstanding example where flooded rice irrigation has been a success is the Mwea rice scheme in Kenya; but here discipline was imposed from the start because the settlers were Mau Mau detainees and the Kenyan Government, to its credit, has continued with firm but sympathetic management. The effect of this discipline was to introduce tractor driven rotavators in 1960, 10–15 years before they made an appearance in SE Asia.

5. Mountain-zone irrigation

Before passing from the immense irrigation areas of SE Asia (similar areas exist in India and China) and describing water control problems in the equally important arid zones, it is instructive to comment on the smaller scale irrigation that exists in mountain zones.

In addition to the problem of economy of water use, irrigation in the Himalayas, Andes, and the hill areas of SE Asia poses two problems: first, how to prevent soil erosion; and secondly, how to minimize catastrophic landslides caused by soil saturation.

Both problems can be resolved by the control of water. Figure 3 shows the scale of the problem, whose essence is well described by quoting from the F.A.O. (1984) report on the Tashigang and Mongar Area Development Project in eastern Bhutan:

> ‘The need to abstract water at elevations of approximately 2000 metres above sea level and convey and distribute it over hillsides with upwards of 30° slopes before discharging surpluses at elevations as low as 1000 metres is a formidable water control task.’

A way of reducing this control problem is the traditional one of dropping water from terrace to terrace; but although this partial solution is dictated by gravity and the need for level growing platforms, it is not so easy to achieve when constructing schemes *ab initio*. Ancient terraced schemes like those in Nepal, the Philippines, Indonesia, and Peru have taken centuries to reach maturity and the problem when initiating new schemes, with the considerations of economic timescales, farm incomes and labour availability, is to know what terrace sizes fit which slopes, and what help does one family need to terrace its soon-to-be irrigated land? Although there is, at first sight, nothing new here for science to investigate, the geometry of the slopes and the human considerations are very real as shown in figure 4 and tables 1 and 2. Figure 4 depicts the basic geometry and table 1 shows the effect of varying the height of a terrace on the volume of earth to be moved and the amount of land lost to cultivation as a result of the terracing.

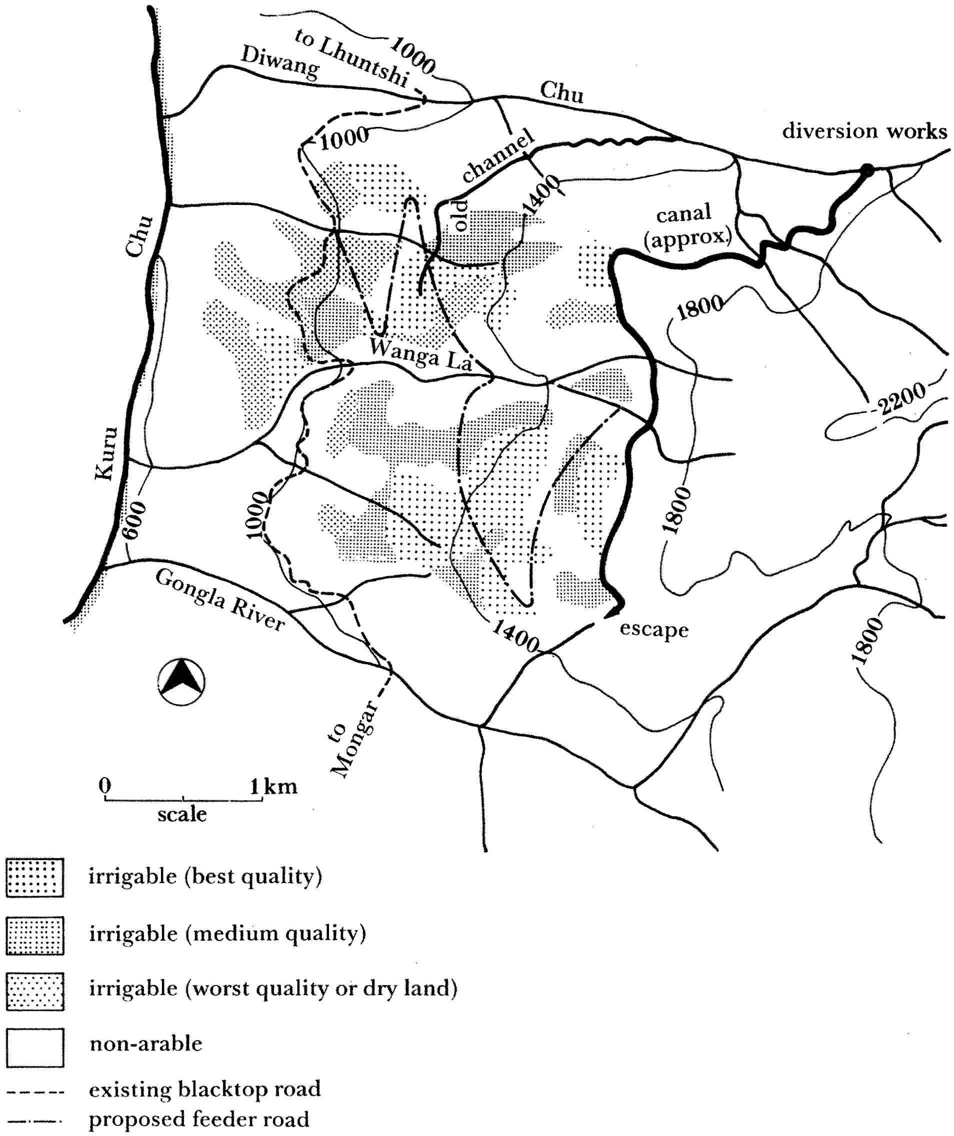

FIGURE 3. Chali irrigation scheme, Kingdom of Bhutan.

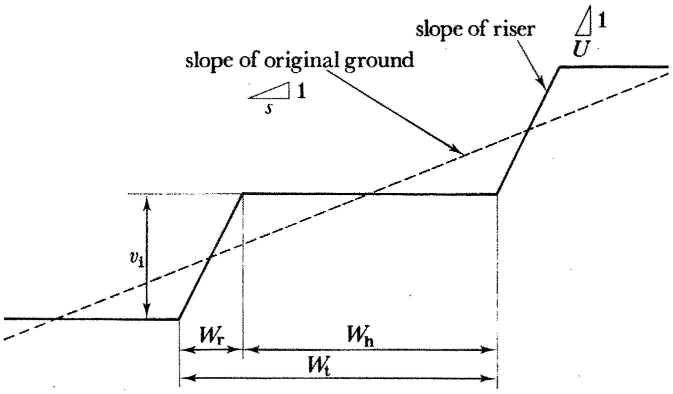

FIGURE 4. Cross section of terracing (see table 1 for symbols).

Table 2 shows the labour problems a family faces when expected to terrace its land. These illustrations remind planners and research workers of the practical problems involved in the control of water and of the disastrous results of uncontrolled water destroying a farmer's land by erosion and landslides. In these circumstances it is pertinent to repeat the questions of §3*a*. Is it necessary to saturate the land to grow rice? Can plant breeders produce varieties for all

Table 1. Terrace sizes and excavation for various land slopes

Source: F.A.O. (1984)

symbol	unit	slope						
		31° (60 %)	31° (60 %)	31° (60 %)	26.6° (50 %)	26.6° (50 %)	22° (40 %)	22° (40 %)
V_i	m	1.25	1.25	1.5	1.5	1.5	1.5	1.5
u	ratio	0.5	0.75	0.75	0.5	0.75	0.5	0.75
W_b	m	1.458	1.146	1.38	2.25	1.88	3.0	2.63
W_r	m	0.625	0.938	1.13	0.75	1.13	0.75	1.13
W_t	m	2.083	2.084	2.51	3.00	3.01	3.75	3.76
L	m ha^{-1}	4800	4798	3984	3333	3322	2666	2660
A	m^2	6998	5498	5498	7499	6245	7995	6996
P_b	percentage	70	55	55	75	62	80	70
C	m^2	0.228	1.179	0.26	0.42	0.35	0.56	0.49
V_a	m^3	1094	859	1031	1400	1171	1493	1312
V_b	m^3	1563	1562	1874	1867	1887	1866	1874

V_i, vertical interval; u, slope of riser (ratio of horizontal distance to vertical rise); W_b, width of bench = $V_i(100-us)/s$; s, slope (percentage); W_r, width of riser = uV_i; W_t, width of terrace = $W_r + W_b$; L, length of terracing = $10^4/W_t$ (m ha^{-1}); A, area of benches = LW_b; P_b, percentage of bench area = $100\,A/10^4\ \mathrm{h}_a^{-1}$; C, cross section at cut = $\frac{1}{8}W_b V_a$; V_a, volume cut and filled per plan hectare = LC; V_b, volume cut and filled per bench hectare = $V/P_b = 10^4C/W_b$.

V_i governs the excavation required per bench hectare, differences are a result of interpretation of significant figures. Slope of riser decides amount of land loss to cultivation.

Table 2. Labour required for terracing (Tashigang and Mongar area development project, Bhutan)

item	value	units
height of terrace riser	1.5	m
volume to be moved[a]	1886	m^3 ha^{-1}
labour output	0.7	man days m^{-3}
labour required to excavate 1886 m^3	1320	man days ha^{-1}
rice holding per family	0.35	ha
labour required to prepare 0.35 ha terracing	462	man days
total family labour available per year	400	days
labour required for farming per year	247	days
surplus labour available for terracing per year	153	days
time taken to prepare 0.35 ha	$462/153 = 3$	years
surplus if family labour increased to 500 days per year	253	days
the time taken to prepare 0.35 ha	$426/253 = 22$	months
if credit available for hire of labour to complete half the work, time taken to prepare 0.35 ha	11	months
amount of credit required at Nu 10 per man day	$462/2 \times 10 = 2230$	Nu[b]

[a] The height of riser governs the excavation requirements per hectare of flat land for any slope.

[b] Nu = Ngultrum (Nu 1.00 = Indian Rp 1.00).

altitudes that will yield as well as flooded rice? Is there some other way of solving the weed problem?

Where designers and researchers could also turn their attention is in devising substitutes for the sand and cement used in water conveyance and control structures. On high mountain schemes sand is usually only found in the valley bottoms. In Bhutan it has to be lifted up to 1 km vertically on the backs of women, children and ponies, with occasional help from a Swiss-style cable crane. The same is true for cement after its journey by road has ended. The result is concrete that soon disintegrates and masonry with a crumbling mortar bond. Answers may lie partly in greater use of indigenous materials such as timber, soil and crop residues, but other ideas involving plastic pipes and sheet would be welcome, providing the costs and benefits are right. The introduction of low-pressure plastic pipes with continuous flow and frequent break-pressure points could be one solution, but so far costs have been too high.

6. Arid-zone irrigation

Although in humid zones there may be a problem in deciding whether to irrigate or not because a crop of some sort can be achieved by rainfall alone, no such dilemma exists in the arid zones of Mesopotamia, northern Africa, and Peru. The inhabitants either perish, migrate or irrigate. A further factor that makes cultivation more difficult for the arid-zone irrigator is the danger of alienating his soil by poor drainage and too free an application of water. Saline soil is likely to result. (This danger in itself suggests whole avenues of intensified research too wide-ranging to be mentioned here, but which the Irrigation Working Party of the Fellowship of Engineering (1985; unpublished) has categorized under 'Effects of fertilizers, pesticides and salts in irrigation water'.) Thus the need to make the best use of water is particularly strong in arid zones near perennial rivers such as the Euphrates, Tigris, and Nile. An example of this need is provided by the Greater Mussayib irrigation project in Iraq. The project (Binnie *et al.* 1983), whose net irrigable area is 61 500 ha is located *ca.* 60 km south of Baghdad in the alluvial plains between the Tigris and Euphrates (see figure 5). Irrigation supply is drawn through a

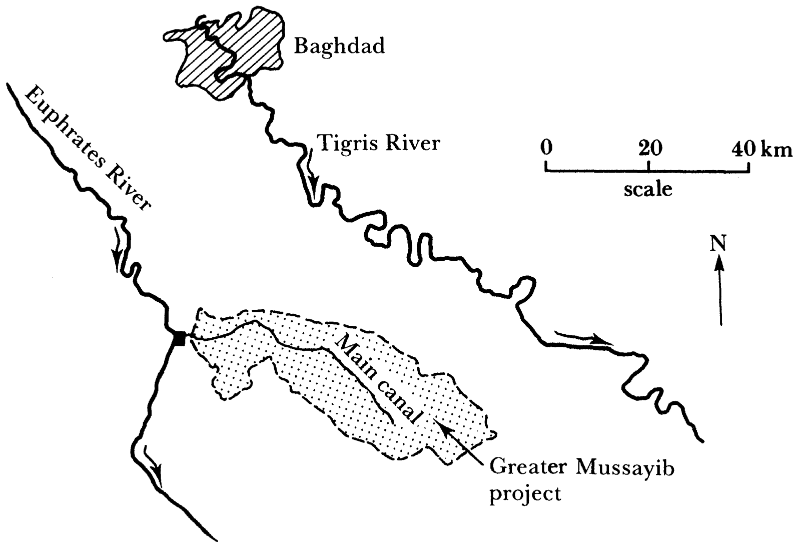

Figure 5. Location of Greater Mussayib project, Iraq.

free intake (that is one without a diversion control structure across the river) on the Euphrates river at Mussayib town about 10 km upstream of Hindiya barrage. The project area extends eastwards from the Euphrates for *ca.* 70 km and its maximum width between boundary drains is *ca.* 20 km; these dimensions indicate the scale of the water control problem faced by the designers.

Irrigated agriculture has been practised in the area for several millennia. Under an ambitious Government programme of land reform and agricultural development, the Greater Mussayib project was conceived in 1951 and constructed during the period 1953–6. Although the project represents a triumph for the Government in terms of social advance, within ten years the project was declared a technical and economic failure because of difficulties over water control, poor drainage (leading to soil salinity) and excessive sediment deposition in the canal system. For salinity control and reduced sedimentation, solutions were adopted by following established drainage design methods and hydraulic modelling procedures, but for water control the design has used techniques previously only to be found on capital-intensive projects.

(*a*) *Water-control strategy*

In deciding what the water-control strategy should be, the design team were influenced by the following factors.

(i) The water allocation to projects in the Euphrates basin does not provide enough water for full summer and winter irrigation. A restriction therefore has to be imposed on the cropping intensity, and high efficiency of water use is essential.

(ii) The need for high efficiency of water use means that water escaping from the project must be kept to a minimum. Traditionally, waste water passing through tail escapes has not been regarded as a serious matter. On many schemes the waste has been returned to the rivers and has been available for use downstream. Increasing salinities have led to the proper decision to collect all drainage waters in Central Iraq into a main outfall drain and lead them directly to the Arabian Gulf. Thus all waste water from irrigation projects, even if of re-usable quality, will be lost to the system.

(iii) Peasant farms occupy 64 % of the total net irrigable area of 61 500 ha. In view of the first two factors it is essential that a cropping pattern is agreed for each season and that the project management provides the farmer with the appropriate discharge. Operation of the system supplying the peasant farmers is therefore in accordance with a pre-determined schedule, modified by the extent of the surplus or shortage at the tail of each distributary canal.

(iv) These factors point the way to a control system that should be as fully automatic as possible. This approach was strengthened by the decision to use centre-pivot irrigators on the state farms which occupy 21 % of the irrigable area. The large pumping load entailed could be shed during a power failure and therefore an 'on-demand' system control is desirable which, as nearly as possible, adjusts the water supply instantly and so prevents wastage.

(*b*) *The control system*

To meet the factors described above the control systems illustrated in figure 6 were devised.

For the intensification of peasant farming, farms of about 17 ha each are grouped into blocks of five (on average), and each farm receives water in rotation for 12 h every $2\frac{1}{2}$ days. Thus, as stipulated in §6*a*, water is supplied to the end user in accordance with a predetermined schedule. The amount of water delivered into each watercourse through the turnout gate from

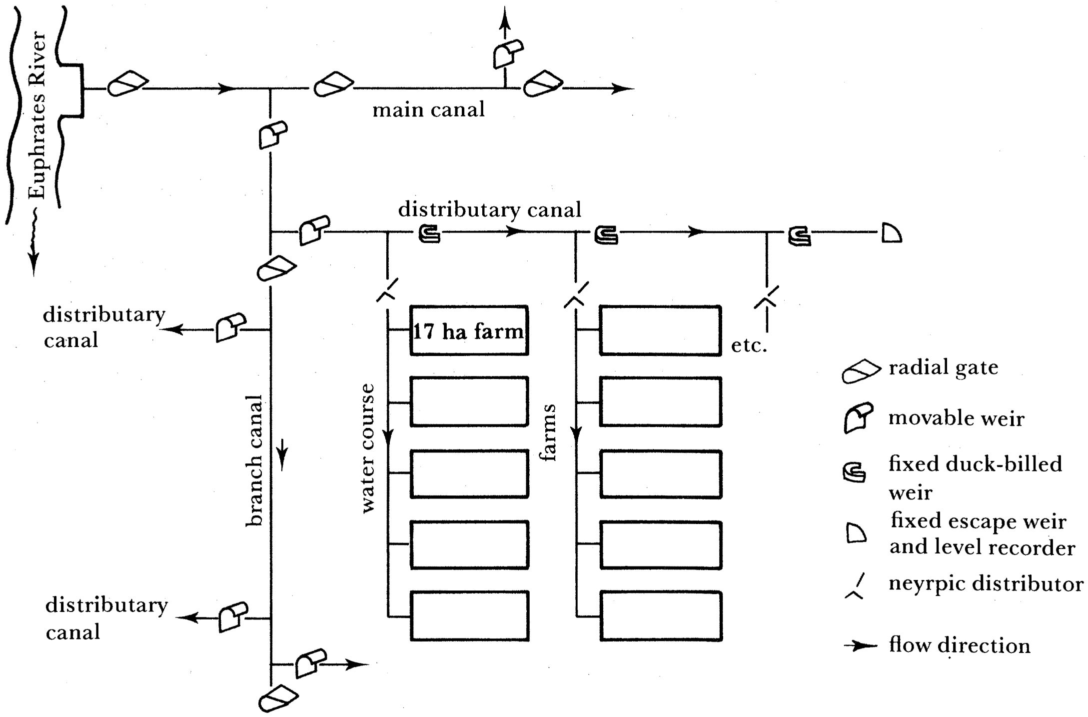

Figure 6. Greater Mussayib irrigation project. Sequence of canal control structures.

a distributary is set manually by a water supervisor. The way this is achieved is shown in figure 7. The values of these manual settings are summated by plugging a hand-held keyboard into an intelligence control unit at the distributary head regulator. With this information the distributary head regulator will automatically maintain the depth required over its movable weir to ensure delivery of the total flow set at the turnouts. From this point upstream the system becomes completely automatic, responding to the downstream demands.

To reduce wastage, a water-level measuring device is located at the tail escape of each distributary. Readings from this instrument are periodically transmitted to the intelligence control unit at the distributary head regulator, which is adjusted either to prevent too low a tail water level or if the tail escape begins to operate. The setting of the head regulator does not therefore remain as keyed in by the water supervisor but adjusts itself to maintain, as far as possible, the sum of the downstream turnout flows, which is the flow demanded.

(c) *Operation and maintenance*

The control methods described above are radical departures from traditional ones. For these methods to work requires an equally radical approach to operation and maintenance. That modern, electronically controlled, equipment can operate successfully (and this implies a successful maintenance organization) in Iraq is self-evident. Television and radio broadcasting, telephones, telex systems, microwave and satellite communications, air-traffic control, aeroplanes, petrochemical plants, power stations, and a host of other examples are all successful operations.

In the agricultural sector, there is no background to this type of technology. Irrigation facilities have always been of the simplest possible technology; operation has, in general, been

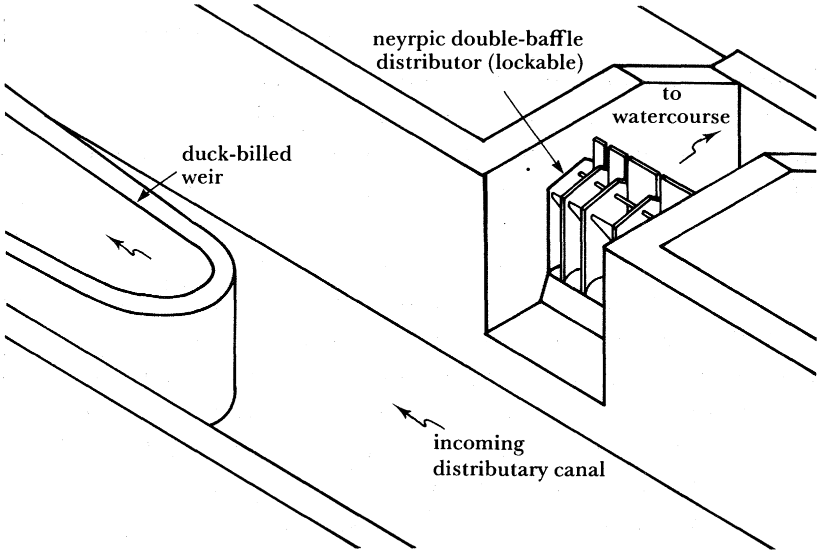

FIGURE 7. Watercourse turnout gate from distributary canal.

crude: often based on a simple 'fully on' or 'fully off' method, and maintenance has been poor. Iraq is now moving into a new era of shortages of water, particularly on the Euphrates river. Irrigation techniques must henceforth be directed towards maximizing production per unit of water used. Modern technology can help to achieve this objective but only if it is operated and maintained correctly. How can this be achieved?

First, it is necessary that everybody concerned, from the highest to the lowest, has a deep commitment to make it succeed. Secondly, staff with skills never before used in the agricultural and irrigation sectors will have to be recruited into positions at all levels of seniority; computer engineers, electricians, and so on. Thirdly, a long period of training and gaining experience will be required. In practice this last requirement can really only be adequately achieved in one way; by contracting out the operation and maintenance to the manufacturers of the equipment for a period of several years, during which time staff would act as counterparts to the contractors. This concept is not new to Iraq although it may be new to the agricultural sector.

(*d*) *Further studies*

The automatic control system described in outline here aims to economize in water use by making canals, as far as is possible practically, respond like the flow in closed conduits. Further research would be beneficial in investigating the lessons to be learnt in the systems already installed, for example, what further automation might be possible downstream of the distributary gates and the hydraulic stability of the system? It might be thought that such control systems have only a limited place in peasant irrigation schemes; yet experiments are currently underway in Sri Lanka to install 'on-demand' closed-conduit systems in flooded rice irrigation areas (Merriam 1984). It is true that the experiments do not yet require the use of electronics because sufficient head is available to use a pressurized automatic system and the areas served so far are small, but the trend to more efficient control systems has begun. Simpler versions of the system proposed for Iraq may have a place in the humid tropical plains too, particularly for the control of water in main and branch canals.

7. Drought-stricken arid-zone irrigation

The sophisticated water control that is beginning to occur on arid-zone irrigation schemes applies particularly to those areas which are endowed with perennial water, have a long tradition of irrigation, favourable soils, and that are blessed with governments with access to development budgets boosted by oil revenues. But what is the situation in say, Ethiopia, or the Sahel? There the requirements are twofold. First, the inhabitants need help in improving rain-fed agriculture, and secondly they need help in conserving or abstracting what little water is available and in developing farming systems that make the best use of their land and water. Thus, at first sight, there seems little that irrigation science alone can do for these areas; it is more a question of painstakingly applying the social and managerial lessons learnt elsewhere to new projects, and building on the partial successes achieved as existing land-development projects lurch from apparent completion towards partial failure and the need for restructuring. Droughts alone are not the sole cause of rural poverty in Africa; governments have neglected peasant agriculture in preference to a communal approach and for industrial and military projects. They have not understood that the cornerstone of economic progress is a strong, independent, agricultural sector. However, in spite of this grim situation, help from the plant breeders seems to be at hand. The *Economist* (2 February 1985) states:

> ‘Increases in agricultural productivity in every part of the world, except relatively uncrowded Africa, are now coming from higher yields per acre than from taking more acres under cultivation...Hardy new varieties of these crops [sorghum, cassava, teff] could soon do for Africa what improved strains of wheat did in Punjab...’

8. In conclusion

In his John Findley Green Lecture, delivered at Westminster College, Fulton, Missouri, 17 years ago, C. P. Snow said:

> ‘All these statements (overpopulation and food shortage) are cliches, dreadful cliches, the most dreadful of all is that many people in the poor countries are going to starve to death before our eyes...or to complete the domestic picture, we shall see them do so before our television sets.’

That prophecy is beginning to come true and it is to help prevent such a reality that this symposium has been called and to which this paper has addressed itself, so far as peasant irrigation and the use of scarce water resources is concerned.

References

Binnie and Partners & International Business Consultants 1971 *Appraisal of the Dumoga Irrigation Project*. Republic of Indonesia: Dir. Gen. Water Resources Development.

Binnie and Partners 1983 *Greater Mussayib project, explanatory report*. Republic of Iraq: Higher Commission of Euphrates Basin Projects.

Clark, J. F. F. 1985 *Note on irrigation efficiencies*. (To be published.)

Clark, W. M., Bramley, M. E. & Thorp, R. F. 1982 Water requirements for flooded rice cultivation. *Proc. Instn civ. Eng* **73**, 769–788.

F.A.O. 1984 *Report on the Tashigang and Mongar Area Development Project.* Rome: F.A.O.
Merriam, J. L. 1984 *The demand irrigation pilot project in Sri Lanka.* Overseas Development Institute.
Wild, J. 1984 A pumped irrigation simulation study in Central Java, Indonesia. *Bull. Int. Comm. Irrig. Drainage, vol.* 33.
World Bank 1984 *Irrigation VII project completion report.* Republic of Indonesia.

Discussion

M. G. R. Varma (*London School of Hygiene and Tropical Medicine*). Mr Clark referred to 'Project Wallace' organized by the Royal Entomological Society of London in Indonesia. Perhaps it is appropriate that I should say something about irrigation schemes and insect-transmitted human diseases. I am disappointed that this subject did not even receive a passing mention in any of the presentations so far. Irrigation projects, particularly irrigated rice cultivation, is closely associated with viral encephalitis, such as Japanese encephalitis transmitted by rice-field breeding mosquitoes in SE Asia and India. The Kisumu irrigation project in Kenya led to an increase in breeding of anopheline mosquito vectors of malaria. I think it is most important that irrigation engineers should consult experts in other relevant disciplines, including public health, epidemiology, and medical entomology, right from the planning stages of the project.

W. M. Clark. The reason for omitting to mention the relation between irrigation schemes and human diseases was because the paper deliberately concentrated on the single theme of water economy and did not attempt a comprehensive review of irrigation practices. A working party of the Fellowship of Engineering has recently prepared a review on the role of science and irrigation and there seemed to be a danger of plagiarism! The working party's report is referred to in the paper and contains a section in Appendix II (*A desirable national research programme in irrigation*), entitled *Health impact on irrigation.*

As Professor Varma notes, the paper also refers to the 'Project Wallace' expedition, which in addition to investigating forest regeneration and agricultural entomology, will also 'investigate and evaluate the deleterious effects of insects on vectors of disease to man and domestic animals in the Dumoga Valley'. It is also relevant to mention that in 1979–80 Dr J. M. Jewsbury of the Liverpool School of Tropical Medicine was instrumental in forming a Civil Engineers – Schistosomiasis Working Group. This has resulted in Dr Jewsbury running a series of courses at the National Agricultural College Silsoe, on the subject of water-resources development and health. It is also hoped to publish a booklet reviewing the literature on this subject.

In spite of the attention I have described I must of course agree with Professor Varma that irrigation planners must not ignore and cannot be complacent about the links between irrigation and health. I thank Professor Varma for drawing attention to the omission.

R. A. Yates (*Booker Agriculture International Ltd, London*). Mr Clark has shown that the efficiency of use of irrigation water varies tremendously from one area to another, these variations being dependent on many factors but especially the degree of re-use of the water. We have also heard much intellectually stimulating discussion on the social aspects of small-farmer development. Is it possible to generalize about whether small farmers are more or less efficient in their use of water than estate-type organizations? Similarly (referring to Professor Cochrane's paper, this symposium), one wonders whether small farmers can cope with conditions of marginal rainfall as successfully as the larger operators: large-scale wheat cultivation in Western Australia is one example of what appears to be efficient dry-land farming.

W. M. Clark. As a general rule, and because of the restricted water rights that apply today, it is probably true that estate irrigation is more economical of water than an individual small farmer, especially if the latter is close to the source of supply. However, no matter what the size of the enterprise, economy of water use is dependent on one of two factors: a physical shortage of water or the high cost of its provision.

If an abundance of free or cheap water is available, a farm (or a management) will not hesitate to use it in an improvident fashion to reduce water management costs. An example of this situation is provided by the water management practised by the earliest agricultural estates set up in Chile and Peru, where water rights were acquired out of all proportion to the area of land being irrigated and later settlers were able to use the drainage water from their older established neighbours.

On the other hand, if water is scarce or expensive to purchase, as for borehole-owner irrigators, economy of water use will occur without any compulsion.