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On irrigation efficiencies

M.G.Bos
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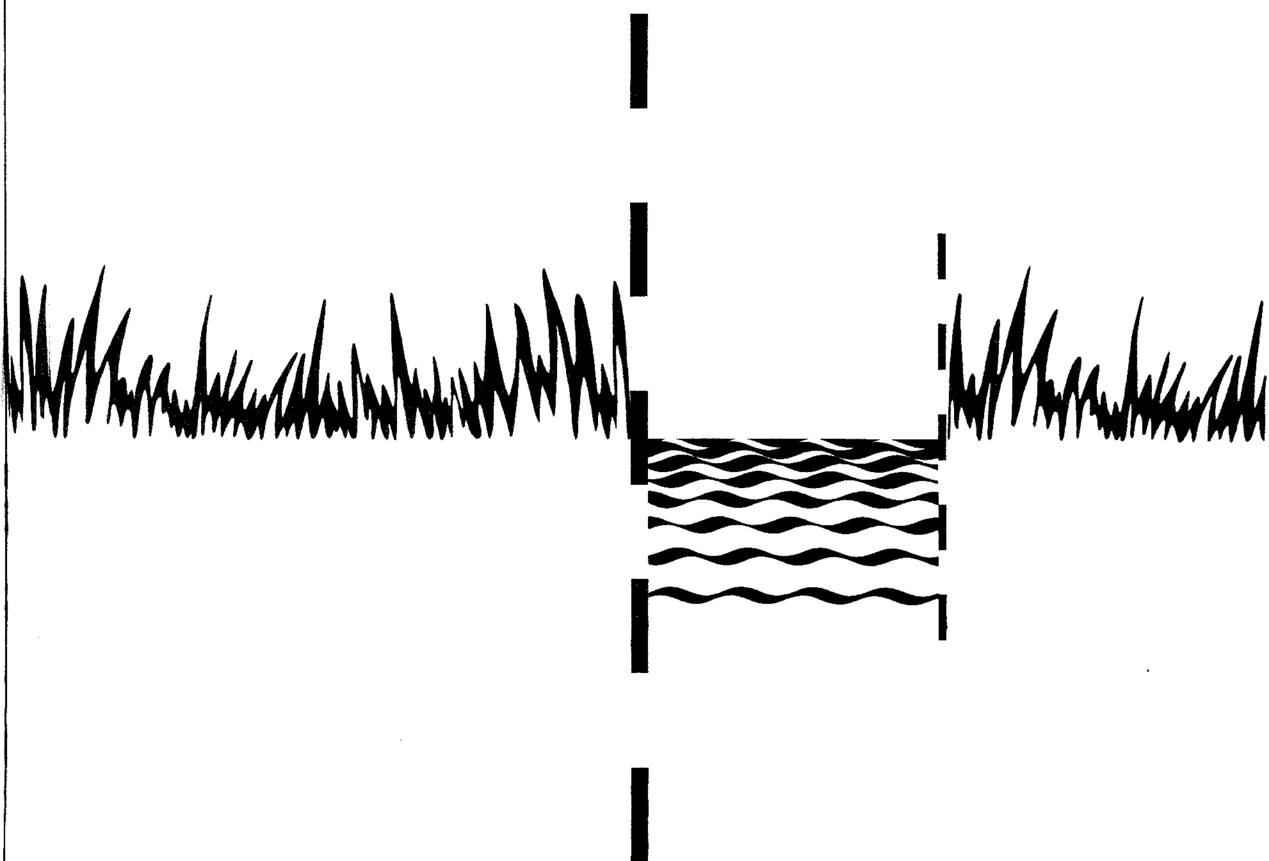

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Fourth edition

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Preface to the fourth edition

This fourth edition has been updated to meet the continuing demand for this publication. Information on irrigation efficiencies, and on the factors that affect these efficiencies, is needed to enable a study of irrigation performance and to improve irrigation management.

To clarify the use of efficiency terminology Chapter 4 has been expanded. Appendix IV has been added to illustrate the concept of target efficiencies. This concept can also be used at canal level.

Wageningen, March 1990 M.G. Bos

Preface to the second and third editions

The second edition of this book has been updated with the use of the standard terminology for irrigation efficiencies as ratified by the ICID Executive Council at its meeting in Teheran in May 1977. A copy of the working document presented at the meeting, 'Standards for the Calculation of Irrigation Efficiencies', is reproduced as Appendix IV.

Wageningen, February 1978 M.G. Bos

Preface to the first edition

This publication is the result of a joint effort by the International Commission on Irrigation and Drainage (ICID), New Delhi, the University of Agriculture, Wageningen, and the International Institute for Land Reclamation and Improvement (ILRI), Wageningen. These three organizations collaborated to collect information on irrigation practices in areas where small farms prevail. The information was amassed by means of a questionnaire, covering no less than 93 items. A total of 29 National Committees of the ICID cooperated in this venture by submitting 91 sets of data covering as many irrigated areas. The workload of the engineers entrusted with the collection of the information has undoubtedly been considerable, and it is due to their enthusiasm and dedication that the results of this inquiry can now be presented.

To my deep regret Prof. Nugteren, who is joint author of this publication, died suddenly on April 20, 1974. Before his death we had been able to complete most of the work. In finalizing this publication I received valuable editorial assistance from Dr N.A. de Ridder of ILRI. I also wish to express appreciation to Mr M. Smith who, on a temporary assignment to ILRI, gave valuable assistance in processing the data.

Wageningen, September 1974 — M.G. Bos

Contents

1	Introduction	9
2	Definition of the problem	10
3	Method of investigation applied	12
4	Data processing	14
4.1	Grouping of areas	14
4.2	Definitions of efficiencies	15
4.3	Calculating the efficiencies	20
4.4	Efficiency terminology and reuse	22
4.5	Accuracy of the calculated efficiencies	23
5	Some results not directly related to irrigation efficiency	25
5.1	Field irrigation method versus irrigated area	25
5.2	Farm size distribution	25
5.3	Number of farms served by group inlets	29
5.4	Project staffing	31
6	Analysis and evaluation of the data from the questionnaire with respect to irrigation efficiency	33
6.1	Conveyance efficiency	33
6.1.1	Conveyance efficiency versus average irrigable area	33
6.1.2	Conveyance efficiency versus size of rotational unit	35
6.1.3	Conveyance efficiency as a function of technical equipment	36
6.2	Distribution efficiency	37
6.2.1	Distribution efficiency versus farm size and soil type	39
6.2.2	Distribution efficiency versus duration of delivery period	40
6.2.3	Farm inlet versus group inlet	43
6.3	Field application efficiency	43
6.3.1	Influence of field irrigation method on field application efficiency	44
6.3.2	Effect of depth of application on e_a	47
6.3.3	Field application efficiency versus farm size and soil type	48
6.3.4	Influence of farm flow rate on application efficiency	49
6.4	Tertiary unit efficiency	50
6.4.1	Influence of flow rate at farm inlet on tertiary unit efficiency	52
6.4.2	Relation of water charges to tertiary unit efficiency	52
6.4.3	Relation of tertiary unit efficiency to method of water supply to the farm	54
6.5	Irrigation system efficiency	55

6.5.1 Relation of irrigation system efficiency to actually irrigated area 56
6.5.2 Influence of project management on irrigation system efficiency 57
6.6 Overall or project efficiency 57

7 Practical application of the study results with some examples 59

8 Evaluation of the applied approach 65

9 Conclusions and recommendations 67

10 References 69

Appendix I Example of a completed questionnaire 70
Appendix II Forms used to calculate water utilization efficiencies 87
Appendix III Tables of basic data as supplied by the questionnaires 91
Appendix IV The influence of uniformity and leaching on the field application efficiency 106
Appendix V Efficiency related terms 115

1 Introduction

In planning and designing an irrigation system, a major problem is to decide what water use efficiency to apply in the calculations. Since basic knowledge on this subject is lacking, it is common practice that this efficiency is either conjectured or derived from existing irrigation systems. Obviously, the efficiency thus obtained is unlikely to suit the conditions of the project area in its future state.

Because water use efficiency is usually the 'guess' factor in the design of an irrigation system, engineers are facing the problem of uncertainty in their calculations. To cover this uncertainty, canals, structures, and reservoirs are being given a greater capacity than would be necessary if objective efficiency standards were available and could be applied. Apart from harmful side-effects, this way of doing things leads to investments that may be considerably higher than would otherwise be necessary.

Obviously, there is an urgent need for more basic knowledge of irrigation efficiencies under different climatological, topographical, soil, agricultural, and socio-economic conditions. In an attempt to shed some light on the matter, an inquiry was organized to find out what methods of water distribution are applied in irrigated areas throughout the world. A carefully planned questionnaire was prepared and tested in close cooperation with a number of National Committees of the International Commission on Irrigation and Drainage (ICID). The answers to this inquiry have revealed a number of interesting features about irrigation efficiencies which were unknown until now.
This publication describes the approach that was applied in the inquiry, the results obtained from it, and the conclusions that could be drawn. These conclusions can be used as a guide in planning and designing new irrigation systems and in studying deficiencies in existing systems.

In the following pages we shall first define the problem more precisely and then describe the method of data collection. Next a brief description of the data processing will be given, followed by a detailed discussion of the results. A sample of the questionnaire, forms used for calculating the various efficiencies, and tables of basic data are given in Appendices I to III, respectively.

2 Definition of the problem

Irrigation is an art that has been practised for centuries. By carefully handling the flow of water and observing the resulting yields, farmers gradually arrived at certain operational standards. These standards had only regional, and sometimes just local, significance. They were aimed at either maximum crop production under the given conditions or at an acceptable amount of labour. Often the standards applied represented a compromise between the two. With more and more land being brought under irrigation, many of these empirical standards were simply copied even when the physical and social conditions in the newly developed regions differed considerably from those in existing projects where they had proved their value. As a result, the effect of irrigation on the yields of the crops, or the labour required for irrigation, can differ greatly from one area to another. Even if these differences in physical and social conditions are well understood, the designers of new projects are still facing the problem of not being able to present a better plan because of a lack of objective standards.

The operational aspects of farm irrigation and water supply systems in areas still dominated largely by tradition do not usually reflect a high degree of water use efficiency as a primary objective. This efficiency, expressed as the ratio between the quantities of irrigation water effectively used by the crops and the total quantities supplied, has only during the last 20 to 25 years been considered an important factor in irrigation. This is not really surprising because up to about 40 years ago our knowledge of the water requirements of crops, more specifically those of evapotranspiration, was only vague and water resources investigations of irrigated areas were not yet receiving as much attention as today.

With water often a limiting factor in countries where irrigation forms a basic element of agricultural production, there is an urgent need for more economical use of the water resources and for a more scientific approach to the problem of operating irrigation systems. This scientific approach does not necessarily involve very advanced or costly methods. It is rather disappointing, for example, that even simple and inexpensive routine tests are seldom conducted with irrigation schedules.

There are three physical characteristics which govern any irrigation operation, in terms of both quantity and time:
- The evapotranspiration by the various crops cultivated and changes in it during the growing season;
- The moisture retention of the soils between field capacity and a preselected depletion limit (the lowest acceptable moisture content that does not significantly affect yields);
- The infiltration rate of the relevant soils.

Other physical factors such as rainfall distribution, topography, and canal seepage may, of course, also play a role, but the above three characteristics must be considered under all circumstances. Further, if one wishes to analyse individualistic versus collectivistic behaviour trends by the farmer population, one must also have a certain minimum amount of information on the socio-organizational structure of the area. Together, all these factors must serve as a basis for defining such operational features as depth, duration, and interval of irrigation for the various crops and soils. But even with this information available, it is only possible to predict the overall irrigation efficiency within an accuracy of 15 per cent at its very best. The assumed percentage of irrigation efficiency in a new project cannot be checked until some 5 to 10 years after its construction, i.e. after farmers and operators have become entirely adapted to the new conditions.

The lack of basic knowledge of water use efficiencies has several serious drawbacks:
- In the planning and design of irrigation systems a large safety margin is applied, as a consequence of which irrigation facilities like canals, structures, and reservoirs are constructed with capacities that are too large;
- Investments are thus considerably higher than would otherwise be necessary;
- The limited water resources are not optimally distributed and used, as a result of which much water goes to waste and less land can be irrigated;
- Last but not least, the low overall irrigation efficiency creates harmful side-effects such as rising groundwater tables and soil salinization. To control the groundwater table a costly subsurface drainage system may be necessary and this will seriously affect the economy of the project.

Photo 1 Over-irrigation has caused a shallow groundwater table, leaving the farmer with a severe salinity problem

3 Method of investigation applied

As a first approach to the problem of irrigation efficiency, it was felt that if a large number of existing irrigated areas could be analyzed – areas whose topography, climate, soils, type of crops grown, and social and organizational structures differ widely – this might at least provide guidelines that could be used with confidence in the planning and design of future irrigation systems.

A proposal to this effect was made by the Dutch National Committee at the Meeting of the International Commission on Irrigation and Drainage in 1967. It was suggested that an inquiry be organized among all the National Committees to obtain information on irrigated areas in each country. The Executive Council of the ICID reacted favourably to this proposal and a small working group was set up to prepare a comprehensive questionnaire. This working group comprised representatives of the Dutch, Israeli, and West German National Committees, at a later stage strengthened by representatives of the Pakistan National Committee. It was agreed upon that the Irrigation Department of the University of Agriculture and ILRI, both at Wageningen, would perform the necessary work involved with the questionnaire and would also be charged with processing the data obtained from it.

It was decided that the questionnaire should cover all possible aspects of water control, agriculture, soils, irrigation, and human society that have a bearing on the water distribution. It was also decided not to place too much stress on economic and sociological aspects, though these undoubtedly have their influence on the quality of the water distribution system. But a limit had to be set somewhere, otherwise the questionnaire would become too unwieldy to produce any worthwhile results.

It was further decided that before distributing the questionnaire proper, a draft questionnaire should first be sent to the National Committees for their comments and amendments and that some trials be made to test the wording and clarity of the questions and the workability of the questionnaire. As a result many suggestions for improvement were received. Some of the suggestions that were adopted were that the inquiry be limited to areas where irrigated farm units of less than 10 to 15 ha prevail and where each farmer is personally involved in irrigating his land, and that participating National Committees be requested to select irrigated areas representing different stages of technical advancement.

The draft questionnaire was tested for its workability in one or more irrigated areas in eight countries. The comments received were used for a further improvement of the questionnaire. During the 22nd ICID Council Meeting in London in June 1971 final approval was given to proceed with the inquiry, and in November 1971 the Central Office of ICID distributed the questionnaire to all National Committees. Each National Committee received a sample of a completed questionnaire, together with an adequate number of blank copies for completion. The questionnaire chosen to act as sample was that from the Guntur District in Andhra Pradesh in India, which was found to suit the purpose best.

At the closing date one year later, 29 National Committees had submitted questionnaires covering a total of 91 irrigated areas. As can be seen from Appendix I, which shows a sample of the questionnaire, the requested information was grouped into four main categories:

A. General information (25 questions)
This category concerned such matters as country, state or province, name of area or scheme, main crops, hectarage, how long agriculture and irrigation has been practised in the area, recent changes, organizations in charge of supply and delivery of water.

B. Water distribution (18 questions)
Here questions were concerned with matters like type of water resources, diversion, storage and regulation facilities, type of conveyance, lift or gravity irrigation, schedule of operation, average total discharges per month, area irrigated monthly, operating agencies, method and schedule of delivery to group inlets, distributaries and farm inlets, average area of delivery and number of farms in one group, staffing organization, cost coverage by water charges.

C. Agriculture (44 questions)
The questions of this category referred to the growing season of the main crops, monthly consumptive use and application, precipitation, irrigation methods, farm size, delivery time, irrigation interval and depth, soil type, soil salinity, presence of groundwater, water charges. Further organizational data were obtained by means of questions on family size, mechanization, collective or individual irrigation, operation by groups of farmers, existence of cooperatives, extension service.

D. Evaluation (6 questions)
In this category the officers supplying the information were given the opportunity to express their opinion on the performance and efficiency of the supply and distribution systems and the field application, on the conflicts between farmers and the distributing organization, and on the communication between farmers and that organization. They could also furnish information on any existing problem of water distribution and desirable or proposed plans for improvement.

4 Data processing

To interpret the huge amount of information obtained from the inquiry it was necessary to process the data in a special way. Various groupings were made on the basis of climatic and socio-economic conditions and others on the field application methods applied. To calculate the various efficiency percentages a special set of forms was devised to which the information from the questionnaire was transferred. Finally the results of the calculations were presented in the form of graphs and tables. The following summarizes the data processing.

4.1 Grouping of areas

Since it was understood that the results of the inquiry could only be of value if the basic climatic and socio-economic conditions were taken as the primary variables, it was decided to group the investigated areas into four main categories:

GROUP I: (a total of 28 areas)
Columbia, Egypt, India, Iran, Israel, Mexico, Rhodesia.
All areas of this group have a severe rain deficit so that crop growth is entirely dependent on irrigation. In general the farms are small and have cereals as their most important crop. Secondary crops, if any, are rice, cotton, or sugar cane.

GROUP II: (a total of 22 areas)
Columbia, Guyana, Japan, South Korea, Malaysia, Malawi, Philippines, Taiwan, Thailand.
Although the economic structure of these countries is about the same as those of Group I (except Japan, see below), Group II differs in that the rain deficit is less and that the main crop in all the areas is rice.

GROUP III: (a total of 32 areas)
Australia, Cyprus, France, Greece, Italy, Portugal, Spain, Turkey, United States of America.
In this group the irrigation season is usually somewhat shorter than in the first two groups, and the economic development, in general, is more advanced. Besides cereals, the most important cultivations are fodder crops, fruit, and vegetables.

GROUP IV: (a total of 10 areas)
Austria, Canada, German Federal Republic, The Netherlands, United Kingdom
The areas of this group all have a cool, temperate climate and a relatively short irrigation season (3 to 4 months). Most of the soils irrigated are light textured and most of the irrigation is by sprinkler and has a supplementary character.

It should be noted that climatic indications only set broad outlines, facilitating the use of the data for comparable areas. It is beyond the scope of this publication to indicate summary areas on the world map to which the data of each group could be applied; here the reader must use his own judgement. Neither were specific indices used for a country's economic situation; Japan, for instance, was included in the second group for the sake of simplicity although it differs from the other countries both as to climate and economic development.

This grouping of areas was not used consistently for the data processing. A second grouping was made on the basis of the field application method used. This resulted in the following four groups:

- Group A:
  Areas with basins for intermittent irrigation. These areas are usually situated on flat land;
- Group B:
  Areas with basins for continuous irrigation. Rice is the main crop in these areas. This group coincides largely with Group II;
- Group C:
  Areas with flow irrigation, including wild flooding, furrow or border strip irrigation;
- Group D:
  Areas with sprinkler irrigation. In general, this group covers Group IV.

Since data were collected under a promise of anonymity to their suppliers, we gave each irrigated area a three-figure code. The first figure stands for a geographical (world) region, the second stands for a country, and the third for an irrigated area or project. The relation between the first two figures of the codes and countries may be of interest and is shown below.

Table 1 Coding of countries

11	Austria	32	Egypt	64	Philippines
12	Fed. Rep. of Germany	33	Iran	65	Taiwan
13	The Netherlands	34	Israel	66	Thailand
14	United Kingdom	35	Turkey	71	Australia
21	France	41	Malawi	81	Canada
22	Greece	42	Rhodesia	82	U.S.A.
23	Italy	51	India	91	Columbia
24	Portugal	61	Japan	92	Guyana
25	Spain	62	South Korea	93	Mexico
31	Cyprus	63	Malaysia		

4.2 Definitions of efficiencies

Water utilization efficiency was used throughout the data processing as the main criterion or characteristic of performance. The use of this single, normative judgement has the advantage that any physical or socio-organizational feature can be tested against the same yardstick, while it also allows a simple prediction of the combined effects of these features when being contemplated for planning purposes. Criteria like crop yields or financial returns per volume unit of water were not applied in the ques-

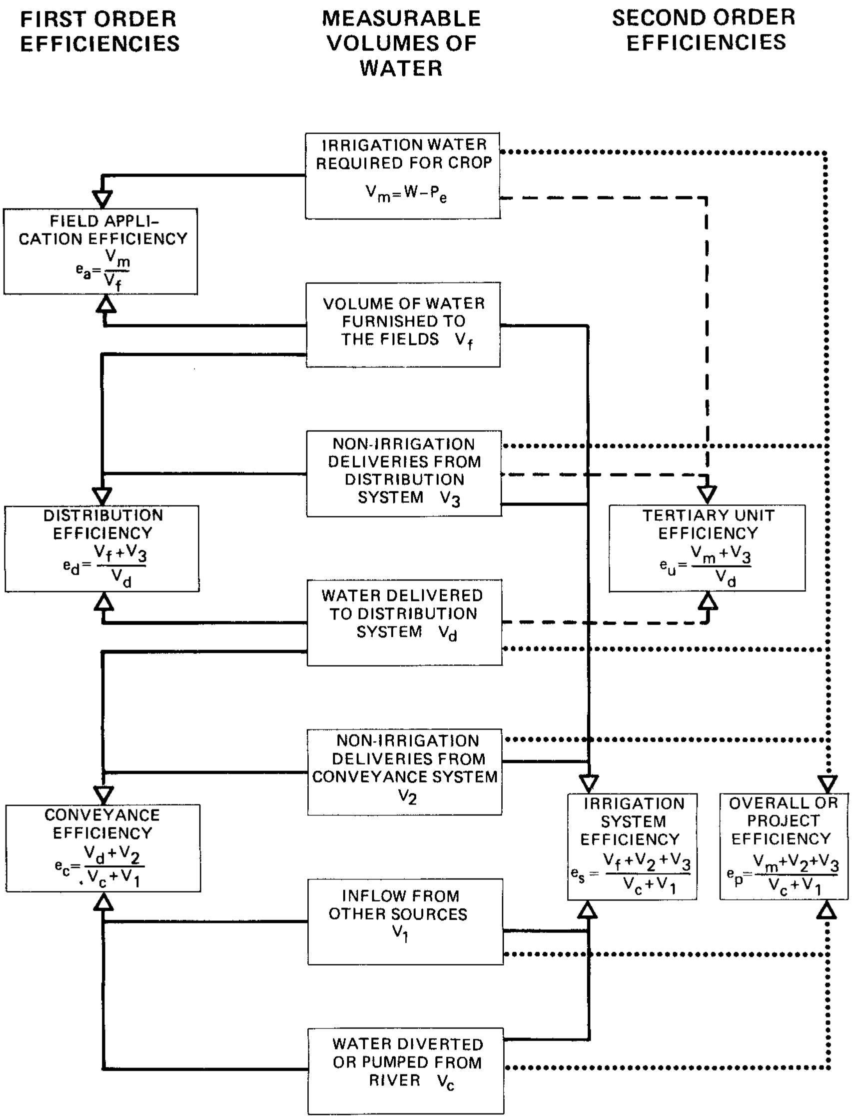

Figure 1 Various efficiencies of irrigation water use

tionnaire, as these would only partially reflect the effects of irrigation. Moreover, the many and wide variations in agronomic and economic conditions would not have allowed comparisons to be made.

The movement of water through an irrigation system, from its source to the crop, can be regarded as three separate operations: conveyance, distribution, and field application.

- Conveyance is the movement of water from its source through the main and (sub)lateral or secondary canals or conduits to the tertiary offtakes;
- Distribution is the movement of water through the tertiary (distributary) and quaternary (farm) canals or conduits to the field inlet;
- Field application is the movement of water from the field inlet to the crop.

The efficiencies of water use in each of these operations, and in three combinations of operations, are defined as follows:

Conveyance efficiency

The conveyance efficiency e_c is the efficiency of canal and conduit networks from the reservoir, river diversion, or pumping station to the offtakes of the distributary system. It can be expressed as

$$e_c = \frac{V_d + V_2}{V_c + V_1}$$

where

V_c = volume diverted or pumped from the river (m^3)
V_d = volume delivered to the distribution system (m^3)
V_1 = inflow from other sources to the conveyance system (m^3)
V_2 = non-irrigation deliveries from conveyance system (m^3)

Distribution efficiency

The distribution efficiency e_d is the efficiency of the water distribution canals and conduits supplying water from the conveyance network to individual fields. It can be expressed as

$$e_d = \frac{V_f + V_3}{V_d}$$

where

V_d = volume delivered to the distribution system (m^3)
V_f = volume of water furnished to the fields (m^3)
V_3 = non-irrigation deliveries from the distributary system (m^3)

Field application efficiency

The field application efficiency e_a is the relation between the quantity of water furnished at the field inlet and the quantity of water needed, and made available, for evapotranspiration by the crop to avoid undesirable water stress in the plants throughout the growing cycle.

The evaluation of the field application efficiency requires the measurement of water deliveries to each field and measurements of soil water content before each application of irrigation water. Although such measurements are certainly needed in research, they are scarcely practicable in the field. An effective system of irrigation scheduling is possible on soils that have a high water-holding capacity or in areas where reliable data on consumptive use and good meteorological data are available. Here, only periodic checks of soil moisture need to be made to ensure that irrigations are made before the soil moisture reaches wilting point and that the application is no more than the remaining water-holding capacity within the rootzone.

The field application efficiency can be expressed as

$$e_a = \frac{V_m}{V_f}$$

where

V_f = volume of irrigation water furnished to the fields (m^3)

V_m = volume of irrigation water needed, and made available, for evapotranspiration by the crop to avoid undesirable water stress in the plants throughout the growing cycle (m^3)

The values of V_f and V_m may be expressed in volumes per area (mm of water depth) per considered period. In areas where reliable data on evapotranspiration and good meteorological data are available, the volume (per area) of water needed to maintain the soil moisture above some undesirable level can be calculated. Then

$$V_m = ET_{crop} - P_e$$

where ET_{crop} is the crop water requirement. This is the total depth of water required, during a specific time period, needed for evapotranspiration and provided by precipitation and/or irrigation when adequate soil water is maintained so that it does not limit plant growth or crop yield (ICID 1978).

P_e is the effective precipitation, being that part of the total precipitation on the cropped area, during a specific time period, which is available to meet evapotranspiration in the cropped area (Kopec, Langley & Bos 1984).

Because the calculation of the total irrigation water requirements of a command area with various crops is time consuming, a simulation programme is used on future studies (Vos et al. 1990).

Water used for leaching, climatic control, soil tillage, seepage, rodent control, etc., is not included in the ICID standard definition of the field application efficiency, because:

- The same crop should be grown with less water under conditions that do not require (some of) these water uses;
- Inclusion of these water uses in the definitions would prohibit the comparison of efficiency values from one area with values from another area;
- Some water needs (e.g. leaching, rodent control) could be covered during the wet season.

Water needs for leaching, however, set the target value for the field application efficiency (Appendix IV).

Apart from these three efficiencies, it was found necessary to define several other efficiencies. The reason for this was that not all the questionnaires had been completed in full detail and others contained answers whose reliability was doubtful because the questions had apparently been misunderstood. To allow a different approach in analyzing these questionnaires, therefore, the following additional efficiencies were defined:

Tertiary unit efficiency.

The tertiary unit efficiency e_u is the combined efficiency of the water distribution system and of the water application process. In other words, it is the efficiency with which water is distributed and consumptively used within the tertiary unit. The tertiary unit efficiency can be expressed as

$$e_u = \frac{V_m + V_3}{V_d}$$

If the non-irrigation deliveries are insignificant compared with the volume of water delivered to maintain the soil moisture at the required level for the crop, which is often true, we may write

$$e_u = e_d \, e_a$$

The tertiary unit efficiency expresses the efficiency of water use downstream of the point where the control of the water is turned over from the water supply organization to the farmers;

Irrigation system efficiency.
The term 'irrigation system efficiency' is not often used, but is included in this publication for the sake of completeness. It is not an ICID standard term.
The irrigation system efficiency e_s is the combined efficiency of the systems of water conveyance and distribution, or

$$e_s = \frac{V_f + V_2 + V_3}{V_c + V_1}$$

If the non-irrigation deliveries are insignificant compared with the volume of water delivered to the fields, which is often true, we may write

$$e_s = e_c \, e_d$$

Overall or project efficiency.
The separate assessments of conveyance, distribution, and field application efficiencies will indicate if and where remedial measures are required to improve the efficiency of water use in the project as a whole. The data used to assess the separate efficiencies can also be used to assess a project's overall irrigation efficiency.
This overall (or project) efficiency can be expressed as

$$e_p = \frac{V_m + V_2 + V_3}{V_c + V_1}$$

This value represents the efficiency of the entire operation between river diversion or other source of water and the rootzone of the crops. If the values of V_1, V_2 and V_3 are negligible compared with V_c and V_m, which is often true

$$e_p \simeq e_c \, e_d \, e_a$$

The above water use efficiencies are ratios of the required volume of irrigation water ($V_{required}$) over the volume of water which is actually delivered (V_{actual}). The efficiency values give information on the water balance of the considered part of the irrigation system. The numerical value of an efficiency does not qualify management. For this purpose the following relation is recommended

$$\frac{V_{required}}{V_{actual}} = \frac{V_{intended}}{V_{actual}} \times \frac{V_{required}}{V_{intended}}$$

The value of the righthand ratio may differ from unity because of all sorts of reasons; it may be too costly to cover all water requirements; water may be in short supply during a dry year; or may be spread thinly over a large command area as done with protective irrigation in India and Pakistan; local water rights may exceed water requirements, etc.

The system designer uses the righthand ratio in selecting and dimensioning the canals/conduits and related structures. The manager subsequently has to cope with this design.

The term in the middle is the ratio of the volume of water that the manager intends to deliver, over the volume that he actually delivers. This ratio thus describes the water delivery performance of the system and may be used to quantify the performance of the system manager.

4.3 Calculating the efficiencies

The values of V_c, V_d, V_f and V_m derived from the questionnaires were converted into mm per month and totalled over the irrigation season and growing season. In those questionnaires which were not complete or where questions had apparently been misunderstood, a reasonable estimate of the missing data was made and indistinct replies were interpreted. Contradictions between different data on the same subject were sometimes found and this problem had to be solved too.

After all the information from the questionnaires had been processed in this way, the various efficiencies were calculated. For this purpose special forms were prepared, an example of which is shown in Appendix 2. The calculated efficiencies are listed in Table 2.

In 18 areas (or 20 per cent of the total), no efficiency at all could be calculated, but in 35 areas (or 38 per cent of the total), 6 efficiencies could be calculated.

The questionnaire used to collect data was difficult to complete for irrigated areas that were poorly managed. In well-managed areas, we may assume that the available water resources are utilized as efficiently as is justified or possible. For many poorly managed irrigated areas, the questionnaire could not be completed, but we presume that their irrigation efficiencies will be lower than the already disturbingly low values shown in Table 2.

Table 2 Calculated (average) efficiencies

Project code	e_p	e_u	e_s	e_a	e_d	e_c
111				.75		
112	.29		.60	.49	*.80*	*.75*
121	.29		.64	.46	*.80*	*.80*
122[1]	.20		.35	.57	*.80*	*.44*
123[1]	*.07*		.30	.23	*.80*	*.38*
124	.60	.63	.75	.81		
131	.57	.70		.88	*.80*	

Project code	e_p	e_u	e_s	e_a	e_d	e_c
132	.41			.41		
211	.31	.33	.79	.39	.85	.94
212	.44	.69	.63	.71	.97	.64
213						
214	.28	.67	*.40*	.70	.94	
215	.46	.56	.69	.66	.85	.82
216		.62				
217						
218		.94				
219		.71				
221	.36	.37	.48	.75	.50	.96
222	.20	.34	.31	.65	.53	.59
223	.30		.51	.59	*.60*	*.85*
224				.63		
231						
232	.20	.36	.36	.56	.65	.56
233	.29	.43	*.47*	*.62*	*.70*	.67
241	.34	*.43*	.46	.72	*.60*	*.77*
251	*.30*	*.33*	.58	.51	*.65*	*.89*
311	*.41*	.51	.78	.52	.96	.81
312				.62		
313	.39	.44	.74	.52	.84	.88
321	.30	*.46*	*.46*	.66	*.70*	*.66*
331	*.29*					
332				.76		
333						
334				.50		
341	*.51*					
351	*.15*	.56	*.22*	*.65*	*.86*	*.26*
352		.61	*.37*	*.70*	*.87*	.42
411						
421	.32	*.45*	.57	.47		.71
422	.49	.86				.56
511						
512	*.40*	.57	.58	.70	.82	.70
513	.14	.20	.34	.40	.50	.67
514	*.25*	*.32*	.47	.53	*.60*	*.78*
515	*.16*	.24	*.34*	*.47*	*.51*	.67
516						
517						
518	.15	.30	.29	.51	.57	.50
519						
51(10)						
51(11)						
51(12)						
611	.34	*.41*	.75	.45	*.90*	*.83*
612	.22	*.23*	.85	.26	*.90*	*.94*
613	.11	.12	.80	.14	.87	.92
614	.25	*.26*	.92	.27	*.95*	*.97*
615	.19	*.20*	.87	.22	*.90*	*.97*
621						
622		.28	*.72*	*.35*	*.80*	*.90*
631	.38	*.34*	*.76*	*.40*	*.85*	*.89*
632		.17	*.54*	*.25*	*.68*	*.80*
633	.33	*.39*	.86	.39	*.97*	*.88*

Table 2 (cont.)

Project code	e_p	e_u	e_s	e_a	e_d	e_c
634						
635						
641				.52		
642	.39	*.43*	.87	.45	*.95*	*.92*
651						
652	.22	.40	.34	.64	.60	.56
653	.33	*.34*	.93	.36	*.95*	*.98*
661				.38		
711				.67		
712						
811	.45					
821	.26		.66	.40	*.80*	*.83*
822	.33		.70	.58	*.80*	*.88*
823						
824	.28	*.53*	.52	.55	*.97*	*.54*
825						
826	.33		.50	.59	*.80*	*.63*
827				.71		
911	.20					
912	.33	*.38*	.78	.42	*.90*	*.87*
913	*.11*					
914	*.13*					
915	.13	*.25*	.33	.38	*.65*	*.51*
916	.19					
921						
931	*.27*	.57	.31	.87	.65	*.48*
932	.51	*.56*	.77	.66	*.85*	*.91*
933	.24	.27	.52	.45	.61	.86
934	.21	.42	.41	.50	.83	.50

values have 50% weight
[1] waste water disposal installations

4.4 Efficiency terminology and re-use

Figure 2 shows the irrigation water supply process and the inflows and outflows which were used to calculate the efficiencies of Table 2. In the black part of the figure, the quantity of water diverted from the river is expressed as 100 per cent. The width of the arrows downstream of the river diversion illustrates the relative magnitude of water quantities in an 'average' irrigation system in Group I or II. Figure 2 shows minor water losses due to evaporation and quite considerable operational losses to groundwater and surface water. These operational losses return to the river – with or without time lag. As a result, the river discharge downstream of the project is higher than one would expect when looking at the river immediately downstream of the diversion.

The downstream river discharge can subsequently be re-used by a downstream irrigation system. Hence the efficiency of water use at river-basin level can be considerably higher than the e_p-value of a single project. It should be realized, however, that return flows can be quite saline and may transport chemicals in the form of pesticides or fertilizer. This is particularly true for return flows because of canal seepage and because of low field application efficiencies.

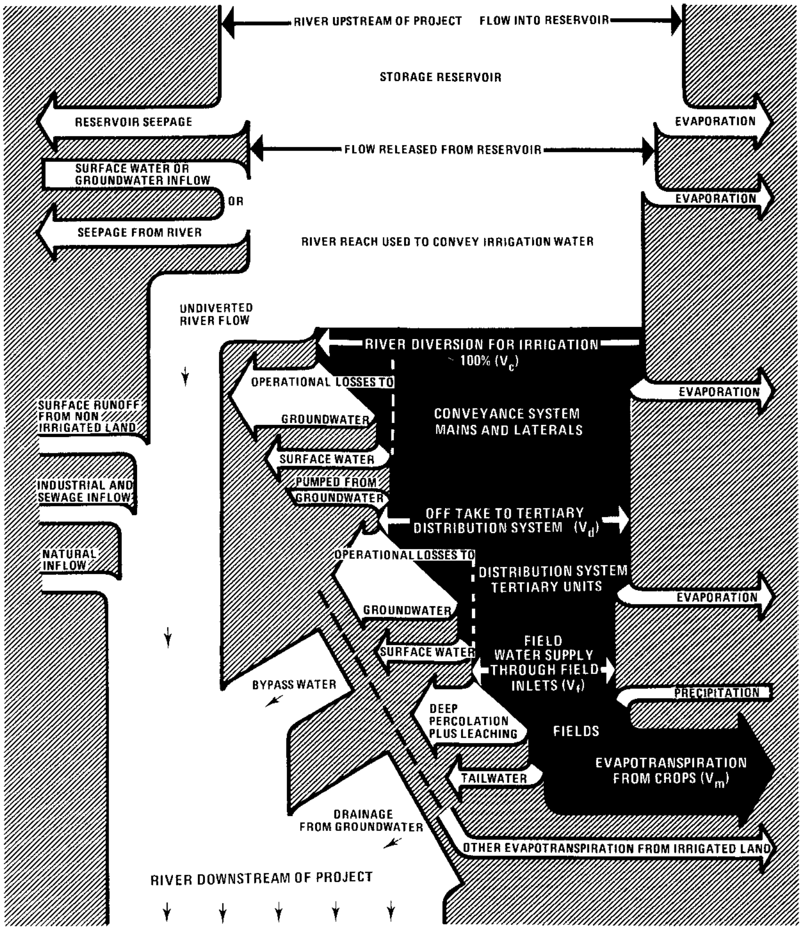

Figure 2 The relative magnitude of quantities of water flowing through an 'average' irrigation system

4.5 Accuracy of the calculated efficiencies

The efficiencies that could be calculated direct from data supplied in the questionnaires, and are therefore considered reliable, are given in normal figures in Table 2. Those that could be calculated after making some assumptions are given in italics. In calculating means, italic values were given half the weight of the efficiencies that could be calculated direct. For this reason the statistical significance of means is limited.

It is further recognized that because the data were divided over four geographical groups the number of samples of each group is too small to enable far-reaching conclusions to be drawn as to correlations of the efficiency with any given phenomenon.

It is obvious that the results presented in this publication indicate trends only and that the individual values of samples are more important than means. With these restrictions in mind, it is still thought that the inquiry and the results obtained from it will serve their initial purpose, provided that the efficiency values are used with caution and under due consideration of the deviations from the mean in each specific situation.

5 Some results not directly related to irrigation efficiency

Although the primary objective of the study was to gain a better knowledge of irrigation efficiencies, the wealth of information produced by the questionnaire also made clear other features of irrigation which are interesting enough in themselves to warrant inclusion in this publication. Since they also indicate something of the approach we took in analyzing and evaluating the irrigation efficiencies, they will be presented prior to the chapter on that subject.

5.1 Field irrigation method versus irrigated crops

From the answers to Questions A8, C10, and C14 it was possible to obtain information on the field irrigation methods applied for various crops. Reliable information was given for all the 91 areas, whose total net irrigation surface was 2.85 million ha. Serving as criterion was the number of times that a specific field irrigation method was used for each of the nine most common crops. These data are presented in Table 3 for each of the four geographic groups.

The table also indicates present irrigation practices in different parts of the world; it shows, for instance, that sprinkler irrigation is only used on a large scale in Europe and North America. Lumped figures for all groups are shown at the right side of Table 3 and are presented graphically in Figure 3.

The results must be considered with a certain amount of caution, because we have the impression that the term 'flooding' was sometimes interpreted to mean that a particular area was inundated by basin irrigation and that other times it was confused with borderstrip irrigation.

5.2 Farm size distribution

In the questionnaire an arbitrary limit was set at about 10 to 15 ha as the maximum farm size prevailing in any area. In the Groups III and IV the information supplied by the National Committees was not particularly restricted to this limit but, far from being a disadvantage, this provided valuable information on the effect that larger operational units have on the efficiencies. From the answers to the Questions A14 and C4 cumulative farm size distribution curves were prepared, showing the percentage of irrigated area where farm units are smaller than a given hectarage (Figure 4).

The curves of Figure 4 are based on information from 84 areas with a total surface of 1 439 300 ha which is irrigated at least once a year. From the answers received to Question A17 we could conclude that the 84 areas are representative of a total area of 4 958 000 ha which, being about 3 per cent of the total irrigated area in the world, may be regarded as a good sample. Areas and hectarages are distributed over the various groups as shown in Table 4.

Table 3 Number of cases in which a water supply method is used as a function of the irrigated crops

CROP	Water supply method used	GROUP I 28 irrigated areas 759 488 ha		GROUP II 22 irrigated areas 397 208 ha		GROUP III 32 irrigated areas 1 586 746 ha		GROUP IV 9 irrigated areas 106 201 ha		GROUPS I to IV 91 irrigated areas 2 849 643 ha	
		No. of cases	Percentage distrib.	No. of cases	Percentage distrib.	No. of cases	Percentage distrib.	No. of cases	Percentage distrib.	No. of cases	Percentage distrib.
Cereals	Basin	8	34			1	3			9	14
	Flooding	2	8			6	19			8	13
	Border strip	4	17			2	6			6	10
	Furrow	9	38	1	100	16	50			25	40
	Sprinkler	1	3			7	22	7	100	15	23
Rice	Basin	8	66	21	88	1	100			30	81
	Flooding	3	25	3	12					6	16
	Border strip	1	9							1	3
	Furrow										
	Sprinkler										
Cotton	Basin	2	11			1	17			3	12
	Flooding					1	17			1	4
	Border strip	3	17							3	12
	Furrow	10	55			3	50			13	55
	Sprinkler	3	17			1	16			4	17
Sugar cane	Basin	1	17	1	50					2	25
	Flooding										
	Border strip										
	Furrow	5	83	1	50					6	75
	Sprinkler										

Turnips	Basin	1	14							1	5
	Flooding	1	14			1	14			2	11
	Border strip	1	14							1	5
	Furrow	3	44	1	100	5	72			9	47
	Sprinkler	1	14			1	14	4	100	6	32
Pasture	Basin	2	50	1	50	2	10			5	17
	Flooding					4	20			4	14
	Border strip	1	25			6	30			7	24
	Furrow	1	25			5	25			6	21
	Sprinkler			1	50	3	15	3	100	7	24
Fodder	Basin	4	36			3	17			7	22
	Flooding	1	9			7	38			8	25
	Border strip					3	17			3	9
	Furrow	5	46			1	6			6	19
	Sprinkler	1	9			4	22	3	100	8	25
Fruit	Basin	3	30	1	100	4	14			8	20
	Flooding					3	11			3	7
	Border strip					1	4			1	3
	Furrow	6	60			9	32			15	38
	Sprinkler	1	10			11	39	1	100	13	32
Vegetables	Basin	3	23	6	100					9	22
	Flooding	1	8			2	12			3	6
	Border strip	2	15							2	4
	Furrow	6	46			8	50			14	34
	Sprinkler	1	8			6	38	7	100	14	34

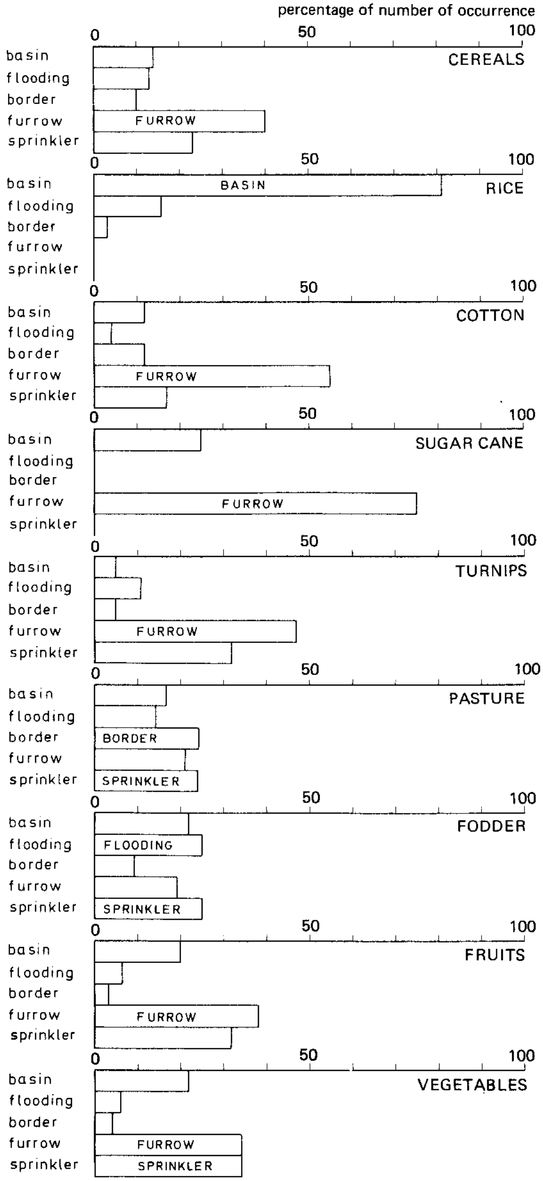

Figure 3 Field irrigation method as a function of irrigated crops (see Table 3)

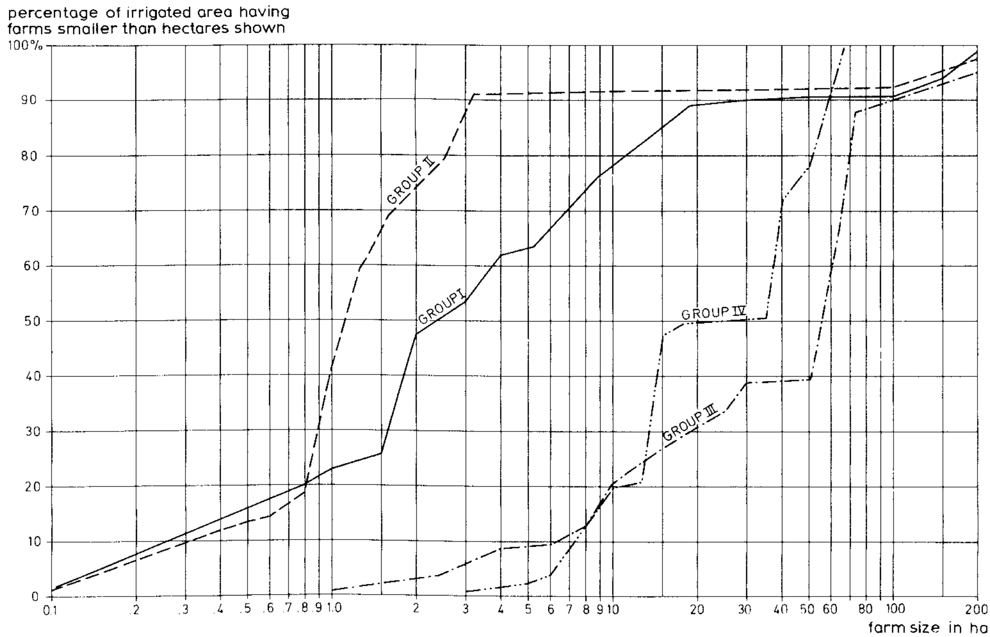

Figure 4 Cumulative farm size distribution curves

Table 4 Irrigated areas and their hectarages distributed over the four geographical groups

Group	Number of irrigated areas	Actually irrigated area (in ha)	Representative of area (in ha)
I	26	683 100	1 851 000
II	20	309 800	1 218 000
III	30	379 200	1 530 000
IV	8	67 200	359 000
All groups	84	1 439 300	4 958 000

5.3 Number of farms served by group inlets

A group inlet is defined here as a collective inlet supplying water to an area in which a number of individual farms or a number of individual (farm) plots are located. The number of farms receiving their irrigation water from a common group inlet is related to the farm size, as is illustrated by Figure 5. It appears that in Groups I and II; where small farm units prevail, more than half of the 50 irrigated areas have inlets which serve between 6 and 25 farms. In Groups III and IV, however, where the mean farm size is significantly larger, the most common method of water delivery is direct to individual farms.

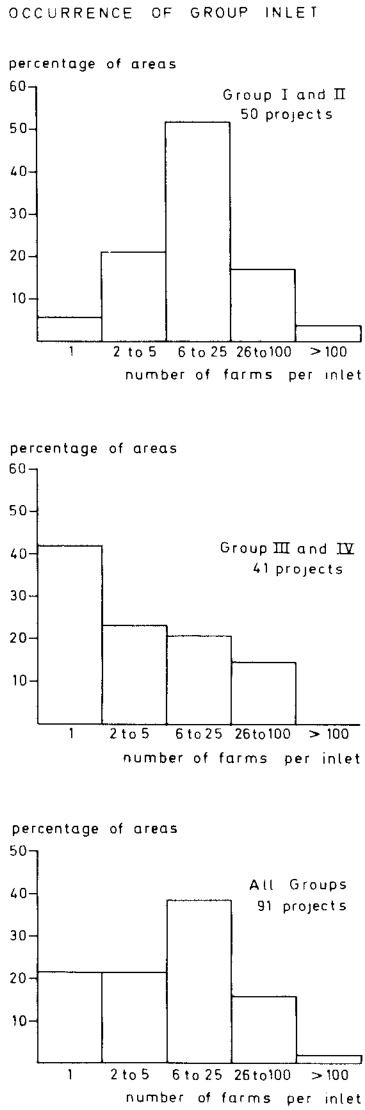

Figure 5 Number of farms served by group inlets

Figure 4 gives a reasonably good idea of the sizes of irrigated farms in the different geographical groups. The reader will recognize the small farms in rice growing areas (Group II), where 50 per cent of the total area is occupied by farms of less than 1.1 ha and 90 per cent by farms of less than 3.1 ha. Group I also has small farms, 50 per cent of its area being occupied by farms smaller than 2.4 ha. There is a marked difference between the size of irrigated farms in the technically and economically less developed countries (Groups I and II) and those in the developed countries (Groups III and IV).

5.4 Project staffing

The number of staff employed to operate and maintain an irrigated area greatly depends on the size of the area. Question B17 asked how many engineers, technicians, overseers, water masters, ditch-riders, gatesmen and watchmen were employed in the area by the managing organization. The total number of staff was plotted against the size of the irrigated area (Question A14). The result is shown in Figure 6.

Although there was a scatter of data due to differences in socio-economic conditions, water supply method, automation, etc., a curve could be drawn representing the average number of staff as a function of the irrigated area.
It was then possible to compile Table 5, which shows the number of staff per irrigation unit (arbitrarily set at 100 ha).

As can be seen, the average number of staff employed per 100 ha decreases as the irrigated area becomes larger, a process that continues until some where between 4000 and 6000 ha. In larger areas the number of staff remains constant at about 0.35 men per 100 ha.

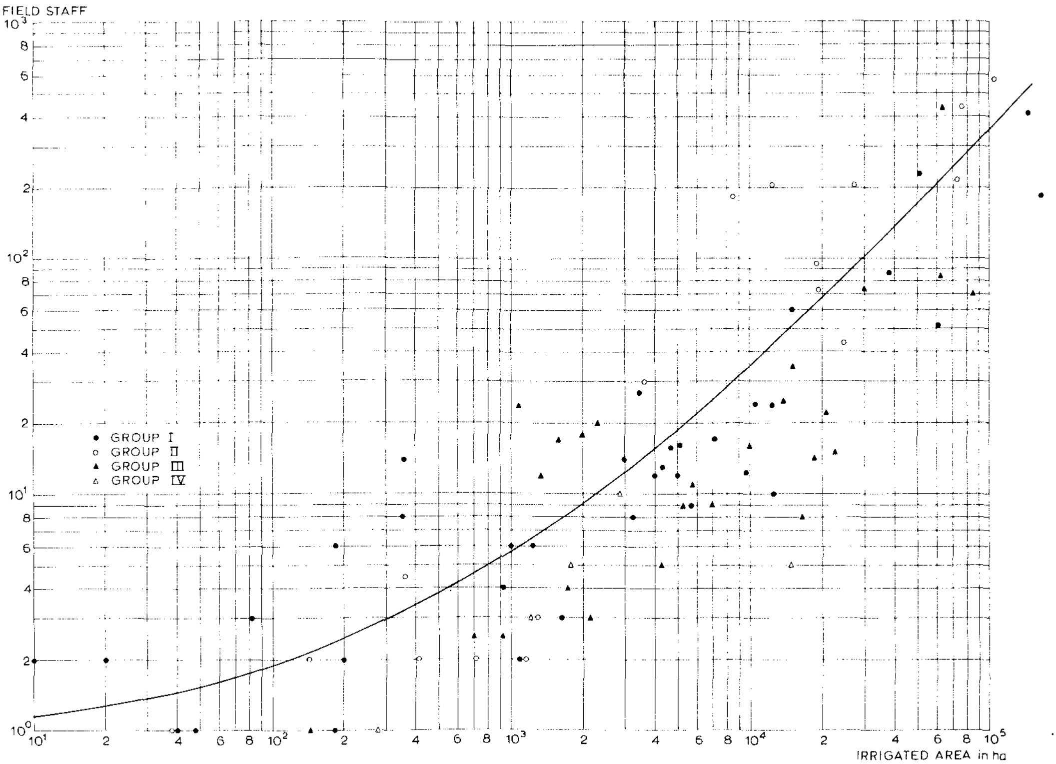

Figure 6 Irrigation project staff as a function of the irrigated area

Table 5 Average project staffing

Irrigated area (in ha)	Average number of staff	Staff per 100 ha
50	1.5	3.0
100	1.9	1.9
300	3.0	1.0
800	5.0	0.63
1400	7.0	0.50
2500	11.0	0.44
4000	16.0	0.40
6000	22.0	0.37
10000	35.0	0.35
50000	175.0	0.35
100000	350.0	0.35

From Table 5 we may conclude that in areas where few management staff are available, irrigated areas greater than, say, 4000 ha are preferable to smaller areas. Obviously, there are more factors that influence the 'best size' of an irrigation project (see Section 6.1.1).

6 Analysis and evaluation of the data from the questionnaire with respect to irrigation efficiency

6.1 Conveyance efficiency

The early irrigation projects of more recent times nearly always received their water by diversion from rivers or from reservoirs. The water losses which occurred in conveying the water to the tertiary offtakes via main, lateral, and sublateral canals were often substantial. Thus the problem of efficient water conveyance has long been recognized. Water conveyance efficiency, e_c, has been defined as

$$e_c = \frac{V_d + V_2}{V_c + V_1}$$

where

V_c = volume diverted or pumped from the river (m^3)
V_d = volume delivered to the distribution system (m^3)
V_1 = inflow from other sources to the conveyance system (m^3)
V_2 = non-irrigation deliveries from conveyance system (m^3)

The above flows can be measured with one of the discharge measurement structures that match local conditions (Bos 1989).

6.1.1 Conveyance efficiency versus average irrigable area

The water conveyance efficiency can be considered a function of the size of the area where technical facilities are available for irrigation. This is illustrated in Figure 7.

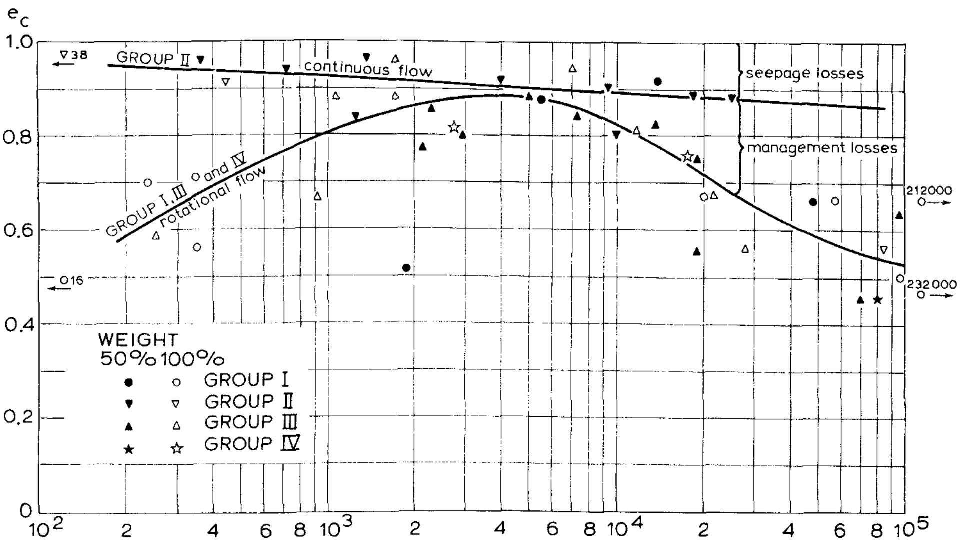

Figure 7 The e_c-values as a function of the irrigable area

(For answers to Question A13 on the size of the irrigable area, see Appendix III, Table A.) Curves for mean e_c-values are shown separately for areas in Group II (rice) and the combination of Groups I, III, and IV.

Group II curve
All areas in Group II have rice as their main or only crop and water is supplied continuously to the fields at an approximately constant flow through a system of canals and ditches. This procedure requires little or no adjustment of division or inlet structures and causes few organizational problems. It is mainly the increasing canal length related to a larger irrigable area that causes the conveyance efficiency to decrease slightly. We assume that most water lost can be attributed to seepage and to a lesser extent to evapo(transpi)ration from the water surface and canal banks.

Groups I, III, and IV curve
This curve represents mean e_c-values for areas where either one main crop (other than rice) or a certain variety of crops is cultivated which may necessitate more or less frequent adjustment of the supply. The curve shows a maximum e_c-value with an average about 0.88 for irrigable areas of between 4000 and 6000 ha. For smaller irrigable areas, e_c-values may be as low as 0.50, probably due to the reduction of the project management to one person who, besides handling the distribution of water, is engaged

Photo 2 Water flowing from an irrigation canal straight into a drain adds to the 'management losses'

in agricultural extension work, maintenance, transport and marketing of crops, administration, etc. If the manager is to fulfill all his tasks satisfactorily, he must be highly skilled, but on small projects (less than 1000 ha) funds are not always available to hire such a person.

Also if the irrigable area is large (more than 10000 ha), the conveyance efficiency decreases sharply, probably due to the problems management faces in controlling the water supply to remote sub-areas. Large systems tend to be less flexible in adjusting the water supply because of the relatively long time it takes to transmit information on flow rates and water requirements to a central office and the long travel time for water in open canals. To avoid water deficits in downstream canal sections, there is often a tendency to increase the supply to the head of the canal system. Here the importance of a communication system and automatic controls is paramount.

In this context it is interesting to note that in the only area (652) of Group II that has an e_c-value not fitting the mean curve, sweet potatoes, sugar cane, and rice are cultivated and the supply to all these crops is on a schedule of rotational flow. It is also interesting to note that the relevant e_c-value corresponds well to the mean curve for irrigable areas in Groups I, III, and IV.

We assume that the difference between the Group II curve and the Group I, III, and IV curve can be mainly attributed to management losses. This water will either be discharged into the drainage system or will inundate non-irrigated lands, creating a drainage problem as a harmful side-effect.

6.1.2 Conveyance efficiency versus size of rotational unit

At the headworks of many irrigation canal systems, water is diverted continuously throughout the irrigation season, its flow rate being adjusted to crop requirements only after periods that are long in relation to the time the water travels through the canal system. Somewhere along the canal system, however, water is drawn continuously via a discharge measuring and regulating structure to serve an irrigation unit with internal rotation to the farms within it. Downstream of such a structure, the canals do not carry water continuously but function on some schedule of intermittent flow. The irrigation unit served by a canal system on intermittent flow is called a rotational unit. Within a rotational unit, the water distribution is organized independently of the overall conveyance and of the water distribution in neighbouring rotational units. It is based only on the farm water requirements in that unit. The size of the rotational unit influences the water conveyance efficiency markedly, as shown in Figure 8 (see Appendix III, Table B). Figure 8 does not include values for Groups II and IV since no irrigation is practised on a rotational schedule in these groups.

Figure 8 suggests that an optimum conveyance efficiency can be attained if the size of the rotational unit lies between 70 and 300 ha. If the unit is small (less than 40 ha) the conveyance efficiency decreases sharply because temporary deficiencies of water cannot be eased by managing the already low flow rate on a different schedule. Because of unavoidable inaccuracies in the measurement of the flow rate, a tendency

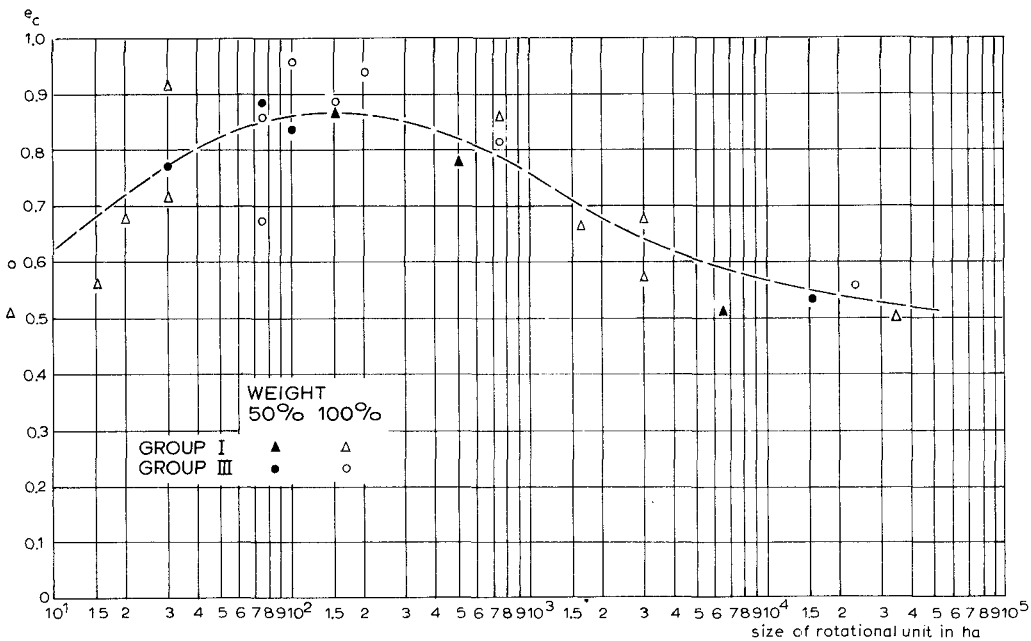

Figure 8 Influence of size of rotational unit on conveyance efficiency (surface irrigation)

exists in small rotational units to set a safety margin above the actual amount required. If the rotational unit is large (more than 600 ha), rather long canals of large dimensions have to be filled and emptied after periods which are short in relation to the time the water travels through the canal. Together with the organizational difficulties of correct timing, rotating the flow in large units causes the conveyance efficiency to decrease to values as low as 0.50.

6.1.3 Conveyance efficiency as a function of technical equipment

It is obvious that no efficient water conveyance is possible without suitable flow-regulating structures and well-constructed irrigation canals. A comparison of relevant data on 15 areas in Group I and 18 areas in Group III is shown in Table 6. Taking into account that the average e_c-values shown in Table 6 indicate an order of magnitude rather than absolute values, we cannot conclude that modern structures or modern canal systems by themselves will improve the water conveyance efficiency (see Appendix III, Table C).
The indicative averages of Table 6 point firstly to a generally better conveyance control in Group III than in Group I, most probably due to a more efficient use of the system's facilities. It seems to make little difference to the conveyance efficiency whether the

Table 6 e_c-values related to flow regulation structures

Group	No controls	Temp. controls	Fixed struct.	Movable gates (manual)	Autom. devices	Others	Average e_c
I	–	.50[1]	.65	.69	–	.48[1]	.65
III	–	.77	.74	.72	.72	.92[2]	.74

e_c-values related to lining of conveyance canals

Group	All canals lined	Main-, lateral- and sublateral canals lined	Main- and lateral canals lined	Main canal lined	All canals earthen
I	.69	.56[1]	.62	.48[1]	.67
II	.72	.69[2]	.79	–	.73

[1] one sample [2] two samples

flow is regulated by fixed structures, hand-operated gates, or automatic controls.[1] The advantage of automatic controls must mainly be attributed to their labour-saving aspects.

As no significant differences are apparent between lined and unlined canals, in either group, the conclusion can be drawn that, at least in the examined areas, linings are applied where soil conditions require the prevention of substantial seepage.

The conveyance efficiency depends above all else on the amount of operational losses. Whether these are small or great will largely depend on whether the management organization is effective or not.

6.2 Distribution efficiency

After the irrigation water has been conveyed to the farm or group inlet through the main, lateral, and sometimes sub-lateral canals, the subsequent stage is its distribution to the various fields. To obtain a reasonable efficiency the distribution network should be well designed and be operated by skilled farmers or a common irrigator representing a group of small farmers. The distribution efficiency has been defined as

$$e_d = \frac{V_f + V_3}{V_d}$$

where

V_d = volume delivered to the distribution system (m^3)
V_f = volume of water furnished to the fields (m^3)
V_3 = non-irrigation deliveries from the distributary system (m^3)

[1] One aspect having a definite effect on the conveyance efficiency is the distribution method applied in the area; see Section 6.4.3

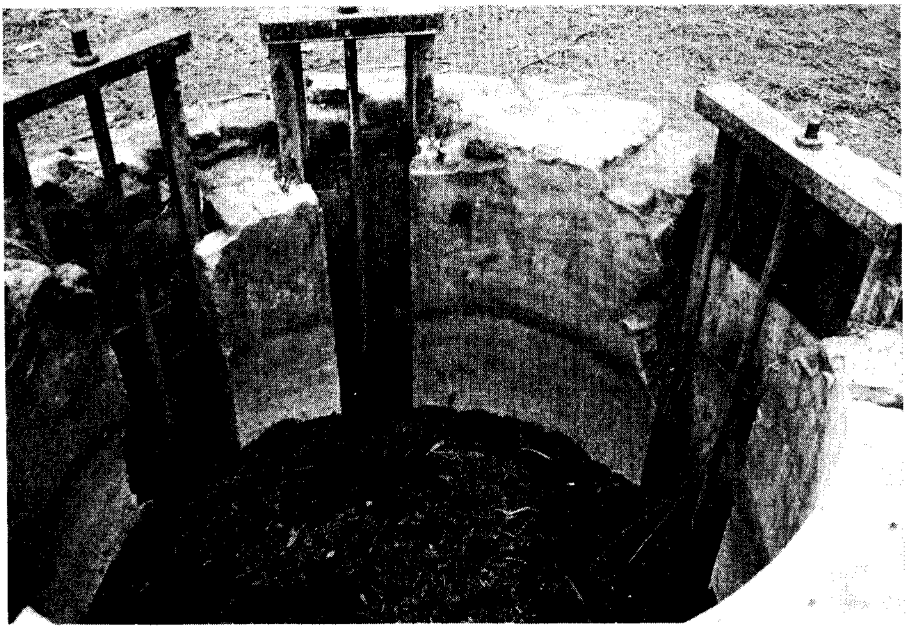

Photo 3 and 4 If structures and lined canals are not properly maintained, they will contribute little to the efficient use of irrigation water

Various factors may influence the distribution efficiency as will be explained below.

6.2.1 Distribution efficiency versus farm size and soil type

The distribution efficiency is affected by possible seepage losses from the distributaries, by the method of water distribution, and by the size of the farms which are served by the distribution system.

Within certain limits of accuracy the influence of these factors can be read from Figure 9 (for data, see Appendix III, Tables D and E). Figure 9 suggests that if small farms (less than about 3 ha) are served by a rotational water supply, the e_d-value is lower than if large farms, say over 10 ha, are served. The reasons for this are that for small farms the water supply must be adjusted at shorter intervals (accuracy of timing) and that the relatively heavy losses at the beginning and end of each irrigation turn cannot be avoided.

If small farms receive their water at a constant rate and it is applied continuously to the field (rice in basin), these operational difficulties do not occur and consequently the distribution efficiency is much higher. If farms have pipelines or lined canals as their distribution system or if farms are situated on less permeable soils (silty clay and clay), the e_d-values are above average.

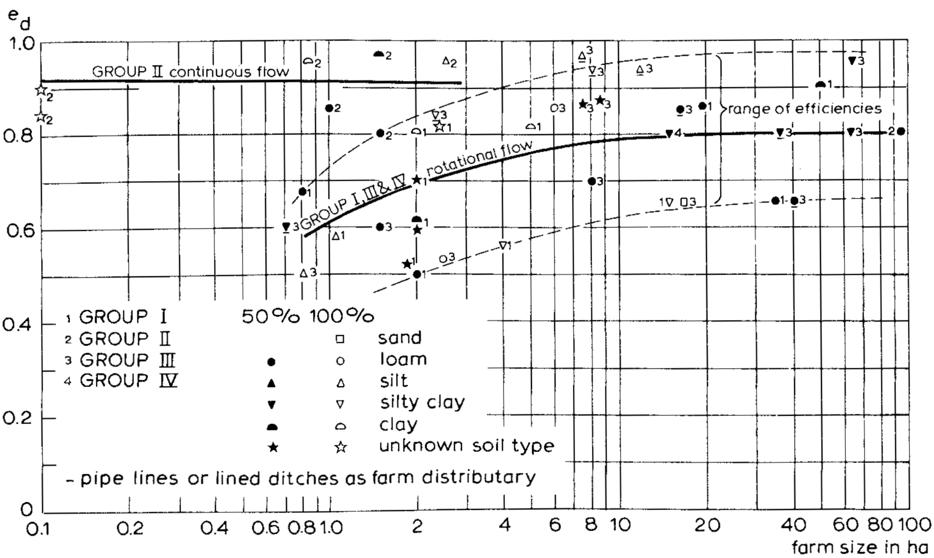

Figure 9 The e_d as a function of farm size and dominant soil type

6.2.2 Distribution efficiency versus duration of delivery period

A farmer receiving his irrigation water on an intermittent schedule and wanting to irrigate a certain hectarage by either basin or flow irrigation must receive a quantity of water during a suitable period if he is to be able to irrigate efficiently. The quantity to be delivered at the farm inlet is to a certain extent a function of the farm size (see Appendix III, Table D).

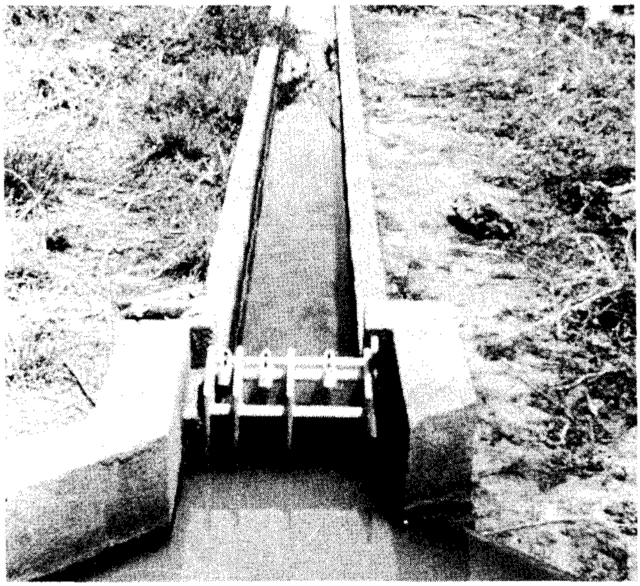

Photo 5 Distribution canals that carry water only for short periods should be lined

Figure 10 shows that in practice the quantity delivered varies widely for a given farm size. No significant correlation was found between the discharge at the farm inlet and the distribution efficiency (see also Figure 17). What does have a pronounced influence, however, is the period during which delivery lasts. This is illustrated in Figure 11. The reason for the relatively low e_d-values if farms have a water delivery period of not more than 24 hours is probably that the losses in intermittently used farm canals consist not only of percolation losses during the operation, but also of those caused by the initial wetting of the soil around the canal perimeter and the final volume of water contained in the canals when the operation is terminated. With an e_d-value equal to about 0.58 for 10 hours, it increases to a maximum of some 0.88 for 200 hours, which is remarkably close to the average value of 0.88 for distribution systems carrying a continuous supply of water to rice fields (see Table 7).

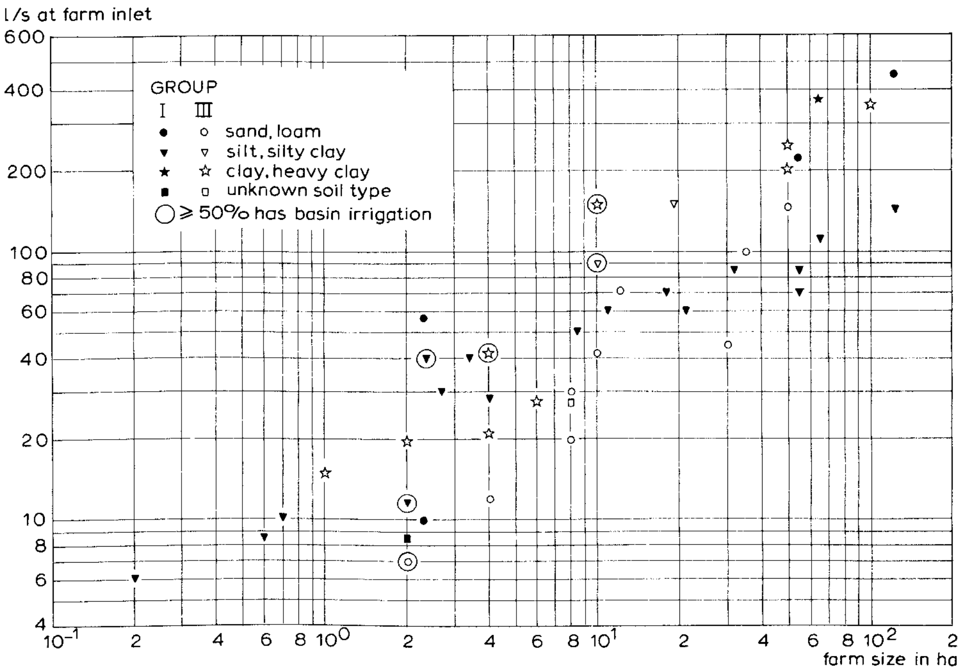

Figure 10 Relation of farm size to discharge at farm inlet

Photo 6 If field canals are not maintained and no structures exist in the distribution system, the efficiency of water use is low

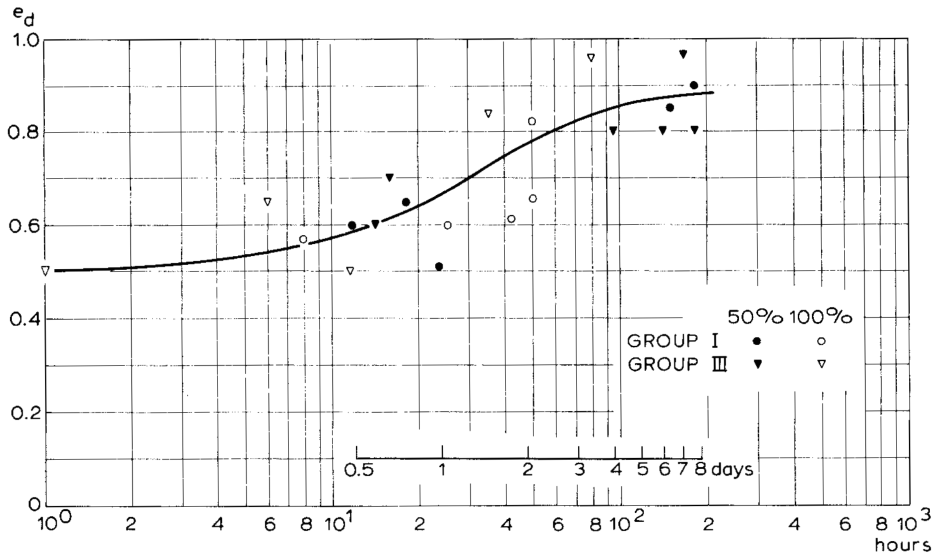

Figure 11 Influence of average delivery period at farm inlet on distribution efficiency (surface irrigation)

Table 7 Distribution efficiency if farm canals flow continuously (Group II)

Code	e_d	Average farm size (ha)
611	.90	0.05
612	.90	0.03
613	.87	0.1
614	.95	0.05
615	.90	0.1
622	.80	1.5
631	.85	1.0
632	.68	0.8
633	.97	1.6
641	–	2.8
642	.95	2.3
653	.95	0.85
661	–	< 5
Average	.88	

To improve the distribution efficiency, we recommend that farm canals be lined, especially those that have a low flow capacity and are used for short periods at a time.

6.2.3 Farm inlet versus group inlet

The median farm size of Group I is small (2.4 ha) and the usual practice is to deliver water to a group of farms via a group inlet, the individual farms (or farm plots) having no inlet of their own. In Group III, however, the median farm size is larger (about 20 ha) and many farms have their own inlet.

Table 8 illustrates this difference in irrigation practice. It also shows that larger farms, i.e. those having their own inlet from the conveyance system, have a more favourable distribution efficiency than farms without an individual inlet. With these larger farms, the management of the distributary system is easier.

Table 8 Type of inlet and its influence on distribution efficiency

GROUP I				GROUP II			
Code	e_d	Group inlet	Farm inlet	Code	e_d	Group inlet	Farm inlet
912	*.90*	x		311	.96		x
915	*.65*	x		313	.84		x
321	*.70*		x	211	.85		x
512	.82	x		212	.97		x
513	.50	x		214	.94		x
514	*.60*	x		215	.85		x
515	*.51*	x		221	.50	x	
518	.57		x	222	.53		x
931	.65	x		223	*.60*	x	
932	*.85*	x		232	.65		x
933	.61	x		233	*.70*		x
934	.83	x		241	*.60*	x	
421	.80		x	251	*.65*	x	
652	.60	x		351	*.86*	x	
				352	*.87*	x	
				821	*.80*		x
				822	*.80*		x
				824	*.97*		x
				826	*.80*		x
Average e_d value	0.68	.67	.69	Average e_d value	.78	.65	.82

50% weight efficiency values

6.3 Field application efficiency

After the water is conveyed through a canal system to the (tertiary) offtake where the farmer (or farmers) distributes the flow to the field inlet, the ultimate goal is to apply it as uniformly as possible over the field, at an application depth which matches the water depletion of the rootzone. The field application efficiency, e_a, is defined as

$$e_a = \frac{V_m}{V_f}$$

where

V_f = volume of water furnished to the fields (m^3)
V_m = volume of irrigation water needed, and made available, for evapotranspiration by the crop to avoid undesirable water stress in the plants throughout the growing cycle (m^3)

The field application efficiency quantifies the water application process downstream, of the field inlet. This process often consists of two parts:
- The water transport part in the field, e.g. (un)lined head ditch, pipe line, tubes;
- The actual application method, e.g. basin, furrows, borders, sprinkler, emitter, etc.

Various factors influence e_a. Several of them could be derived from the data and are discussed below.

6.3.1 Influence of field irrigation method on field application efficiency

The field irrigation method applied has an important bearing on the field application efficiency. Efficiency values for various application methods are summarized in Table 9.

Table 9 Field application efficiency as a function of irrigation method

Group	Average e_a	$4e_a$ per		Field application method	
		Basin	Furrows	Borders	Sprinkler
I	.53	.56	.54	.47	
II	.32	.32	–		–
III	.60	.59	.58	.57	.68
IV	.66	–		–	.66
Average of groups I, III and IV		.58	.57	.53	.67

Note: Flooding was excluded from this table since it appeared the term 'flooding' was sometimes confused with border strip irrigation and other times with basin irrigation.

From the table we may draw the following, rather general, conclusions:
- Provided that topographical conditions are favourable, basin irrigation with intermittent water supply is an efficient method of water application.
- Flow irrigation by border strip and furrow has a rather favourable efficiency, considering the inherent non-uniformity of these methods;
- Continuous basin irrigation for rice cultivation (Group II) has a low application efficiency. This may be attributed mainly to the saturation of the soil profile with its consequent percolation losses, but also to the fact that only very rarely is the supply adjusted in accordance with rainfall. It should be noted, however, that a change from continuous to rotational basin irrigation will not necessarily increase

the overall project efficiency since both conveyance and distribution efficiencies may decrease significantly due to operational difficulties;

- Overhead sprinkler irrigation is, in general, the most efficient method of water application, although the mean application efficiency is less than is often quoted.

Photo 7 Flow irrigation by furrow is a reasonably efficient, but labour intensive, method of water application

The average efficiencies for basin, furrow, border strip, and sprinkler irrigation are presented graphically in Figure 12.

The permeability of the soil in relation to the irrigation method applied influences the application efficiency. With flow irrigation (sloping furrows and borders) the efficiency will also depend on the ratio between advance time and the time of infiltration required to apply the minimum depth. It is often assumed that for normal furrow or border lengths the application efficiency is higher for heavy soils (so with rather long-lasting infiltration) than for light soils. Figure 13 shows average e_a-values for different types of soil and different irrigation methods: (intermittently and continuously) flooded basins, flow irrigation (hence a combination of border and furrow irrigation), and sprinkling. The specific effect that the soil permeability has on the efficiency is most evident with continuous flooding as in paddy cultivation. But then, the most suitable soils for paddy are silty-clay and clay, for which application efficiencies of 40 to 50% can be justified.

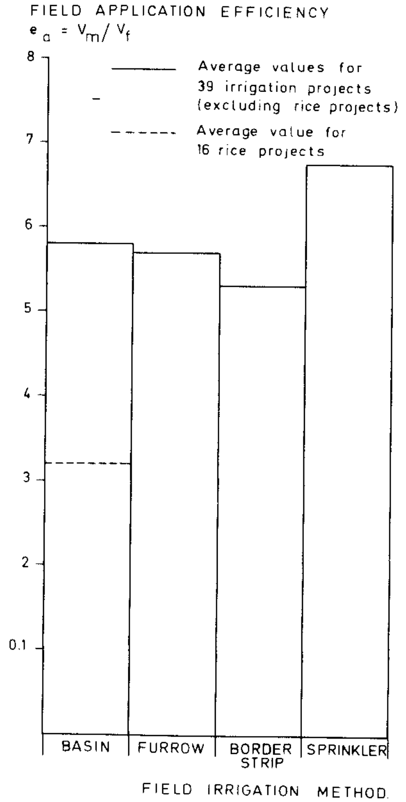

Figure 12 Field application efficiency related to irrigation methods

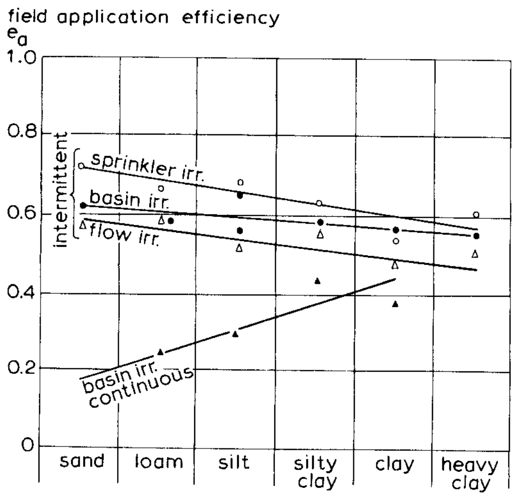

Figure 13 Field application efficiency and method with reference to soil type

Intermittent basin irrigation shows a rather constant application efficiency of 0.58 for all soils, which can be explained by the presence of the almost stagnant water layer over the field during infiltration. With this method the application efficiency seems to depend entirely on the uniformity with which the depth of water is applied. A horizontal basin floor and refined land levelling can contribute much to the efficiency.

With regard to flow irrigation efficiency, Figure 13 would seem to indicate that the irrigation of light soils is handled somewhat more efficiently than that of heavy soils. This is in contrast to the general assumption, referred to above, that flow irrigation is more efficient on heavy soils. If the indicated trend is realistic, the conclusion could be that the special problems of flow irrigation on light soils are well understood and that the field systems are adapted to them: by operating short lengths of run, for instance.

Figure 13 further indicates that (heavy) clay soils are less suitable for sprinkler irrigation, probably due to the low infiltration rate and its sharp reduction with time. If the sprinklers do not have a particularly low intensity, water will be partially ponded on the surface, or, if the land is sloping, surface runoff will occur. Basin irrigation with a continuous water supply has a reasonably good application efficiency on heavy soils.

The average values shown in this figure are based upon data from 26 areas with flow irrigation, 18 areas with intermittent basin irrigation, 12 areas with sprinkler irrigation, and 15 areas with a continuous water supply to basins. (For detailed data, see Appendix III.)

6.3.2 Effect of depth of application on e_a

The purpose of an irrigation turn is to provide water that can be stored within the rootzone of the crop so that the plants can draw on this water during the period between successive irrigations.

In accordance with good irrigation practice, the depth of water applied per irrigation is mainly a function of root depth and the moisture storage capacity of the soil. Figure 14 indicates that the depth of water applied by surface irrigation methods (as against overhead sprinkler methods) has no marked influence on e_a provided that at least 60 mm is applied.

If less water is applied, the technical limitations of surface application methods are such that no uniform water distribution can be achieved, resulting in a low field application efficiency. Overhead sprinkler irrigation can supply a limited depth of water rather uniformly. As shown in Figure 14 sprinkler irrigation is especially suited to supply amounts of less than 60 mm, which can be advantageous for crops with a shallow rootzone.

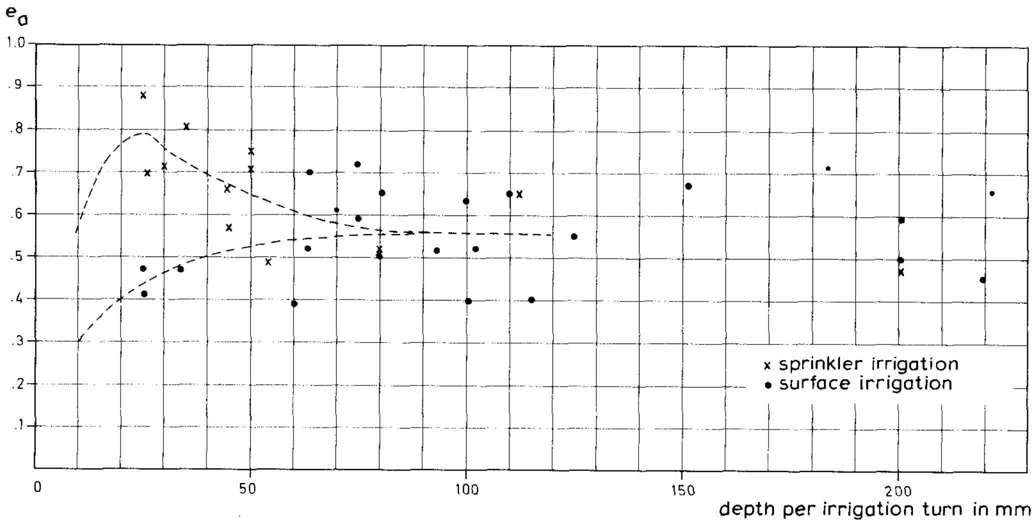

Figure 14 Relation of field application efficiency to depth of application per irrigation

6.3.3 Field application efficiency versus farm size and soil type

Figure 15 shows that no correlation was found between farm size and the efficiency with which water is applied to the fields. Nor does the type of soil on which the farm is situated seem to have any independent influence on the field application efficiency.

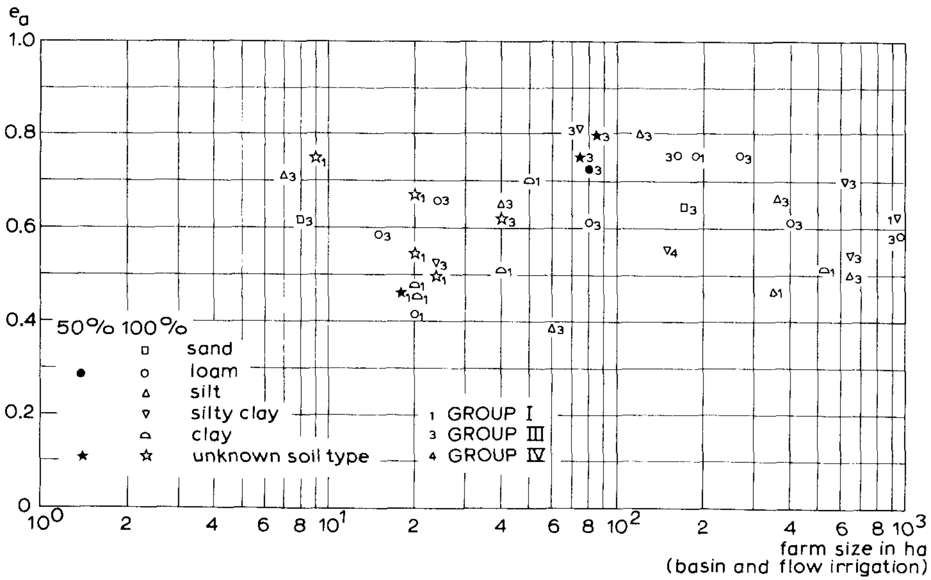

Figure 15 Relation of field application efficiency to farm size and dominant soil type

6.3.4 Influence of farm flow rate on application efficiency

Figure 10 illustrated that farmers utilize a wide range of flow rate to irrigate the same size of farm. By itself, the available flow rate at the farm inlet has no influence on the field application efficiency (see also Figure 17), but it is one of the factors that decides the size of the farm plot that can be irrigated at one time. The flow (l/s) utilized to irrigate a unit surface (ha) farm plot at one time, however, appears to influence the field application efficiency as illustrated in Figure 16.

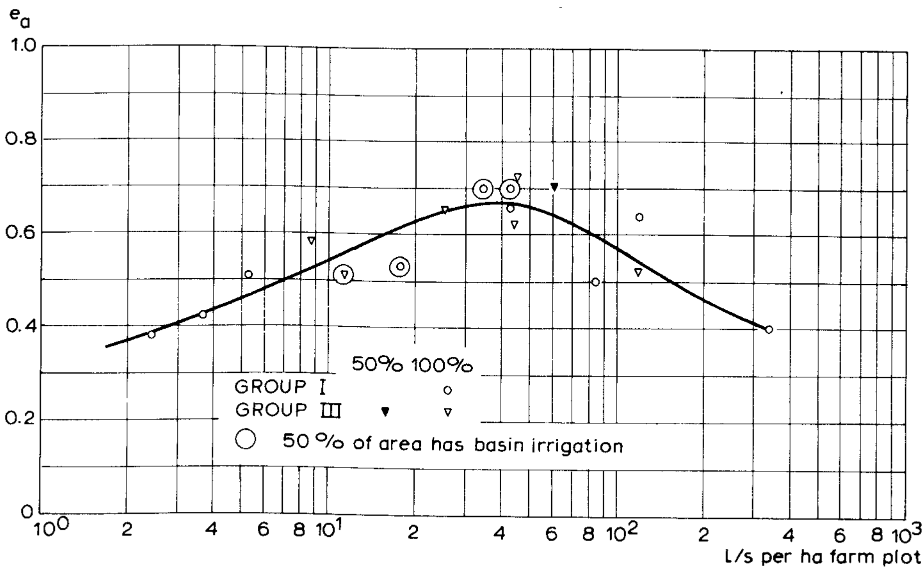

Figure 16 Influence of flow rate per ha farm plot on e_a

The surface irrigation data of Groups I and III reveal favourable application efficiencies for flows of 30 to 50 l/s per ha plot. If the flow rate at the farm inlet is known, it is possible to determine the size of the farm plot that can be irrigated at one time with a favourable application efficiency. (From this, one can calculate the number of plots per farm.) In reverse, if the plot size is fixed, Figure 16 can be used to select a suitable flow rate at the farm inlet.

Photo 8 If a neighbouring fallow field is inundated during irrigation, water use efficiency cannot be high

6.4 Tertiary unit efficiency

A farmer, or a group of small farmers, receiving a volume of irrigation water from the conveyance system, has to distribute this water over the farm(s) and fields, where it is applied to the crops. The tertiary unit efficiency, e_u, is defined as

$$e_u = \frac{V_m + V_3}{V_d}$$

where

V_m = volume of water needed, and made available, for evapotranspiration by the crop to avoid undesirable water stress in the plants throughout the growing cycle (m^3)

V_d = volume of water delivered to the distribution system (m^3)

V_3 = non-irrigation deliveries from the distribution system (m^3)

If the non-irrigation deliveries are negligible compared with V_m, which is usually true, we may write $e_u = e_d\, e_a$. The tertiary unit efficiency thus expresses the efficiency of water use downstream of the point where the control of the water is turned over from the water supply organization to the farmers.

When irrigation requirements are being calculated, the efficiencies in the successive stages of conveyance, distribution and field application will be taken into account. Whereas formerly these efficiency values were merely rough estimates, the material now available makes it possible to derive much more accurate values. By using the figures and tables in Sections 6.1, 6.2, and 6.3, one has a very sound basis for calculations. In this way, the tertiary unit efficiency e_u can be regarded as a product dependent on two independent factors, e_a and e_d. The application efficiency can be based on the criteria of irrigation method and soil (Figure 13), corrected if necessary for depth of application (Figure 14) and flow size per plot unit area (Figure 16). The distribution efficiency can be determined on the basis of farm size and irrigation method (Figure 9), with a positive or negative correction for extremely short or long delivery periods of intermittent farm supply (Figure 11). The tertiary unit efficiency is an important item, not only for farmers wanting to base their irrigation demand on the net field irrigation requirements, but also for water masters and ditch riders preparing the supply schedules. It should be pointed out that in following the above procedure and making any corrections deemed necessary, the following local aspects should be taken into account when calculating the tertiary unit efficiency: irrigation method, soil type, farm size, depth of application, flow size per unit area, and delivery period (the last two factors being reciprocally proportional). Some additional factors influencing e_u are dealt with below.

Photo 9 An offtake equipped with a movable broad-crested weir supplies water to a tertiary unit. Such a structure can measure and regulate the flow rate (Bos 1989)

6.4.1 Influence of flow rate at farm inlet on tertiary unit efficiency

The flow at the farm inlet, which the farmer has to control and distribute as uniformly as possible over his fields, appears to have no influence on the tertiary unit efficiency. (See Figure 17) The farm inlet discharge was also plotted against e_a and e_d, and the result was a similar scatter of points as in Figure 17.

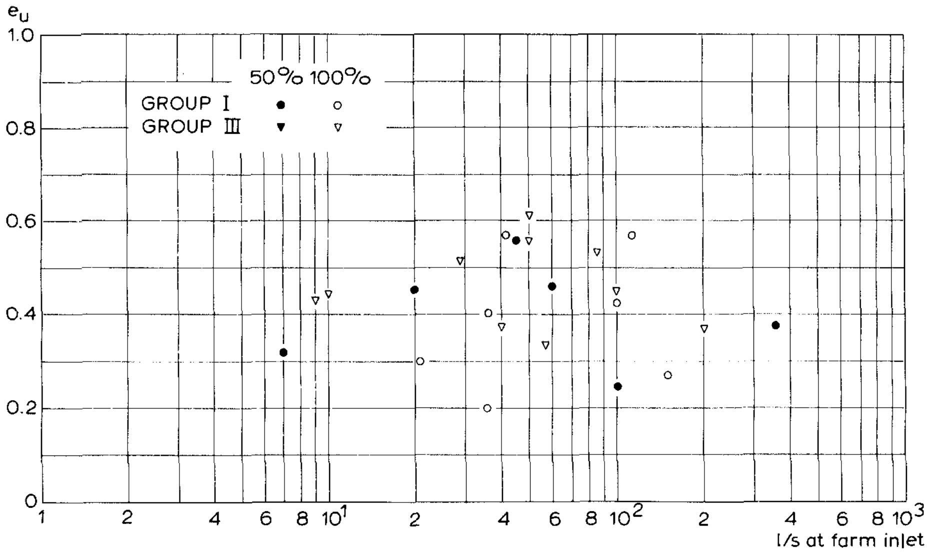

Figure 17 Influence of flow rate at farm inlet on e_u

6.4.2 Relation of water charges to tertiary unit efficiency

One would expect that the price a water user has to pay for his irrigation water would influence its efficient use. Generally speaking high water charges per unit volume should stimulate the water user to handle his available water as well as he can.

From answers to Question C27 it appeared that practically all irrigated areas levy water charges either on the proportionality of water use or on a combination of a fixed amount and a proportional rate. The relationship between water charges and tertiary unit efficiency could be derived from answers to Question B18, and is shown in Figure 18 (see also Appendix III, Table H).

The score on the horizontal axis of Figure 18 was obtained by adding the three scores made by the answers to the Question B18a, b, and c (see Appendix I). If a mark was placed below the heading 'none', 0 was scored. A mark in the rows for operation and management scored 1, 2 or 3 for, respectively, 0-50%, 50-100% and 'complete'. For the row 'capital cost' the score was 4, 8 or 10.

Although both envelopes (having a 90% confidence level) rise with an increasing score, it is doubtful whether higher charges produce a direct effect on the efficiency of water use. Charges made for irrigation water are often well below cost and the marginal productivity of water is usually much higher than this charge. For about 60 irrigated areas, the method of charging for water and the approximate charge expressed in monetary units per ha were analyzed (See Appendix III, Table H).

Large differences could be observed between the charges levied in the same country, but no direct relation appeared between the level of the charges and the e_u-value.

It is more acceptable to state that in those areas where relatively high charges can be levied because of good farm management and high productivity, water distribution and water control on farms is generally efficient.

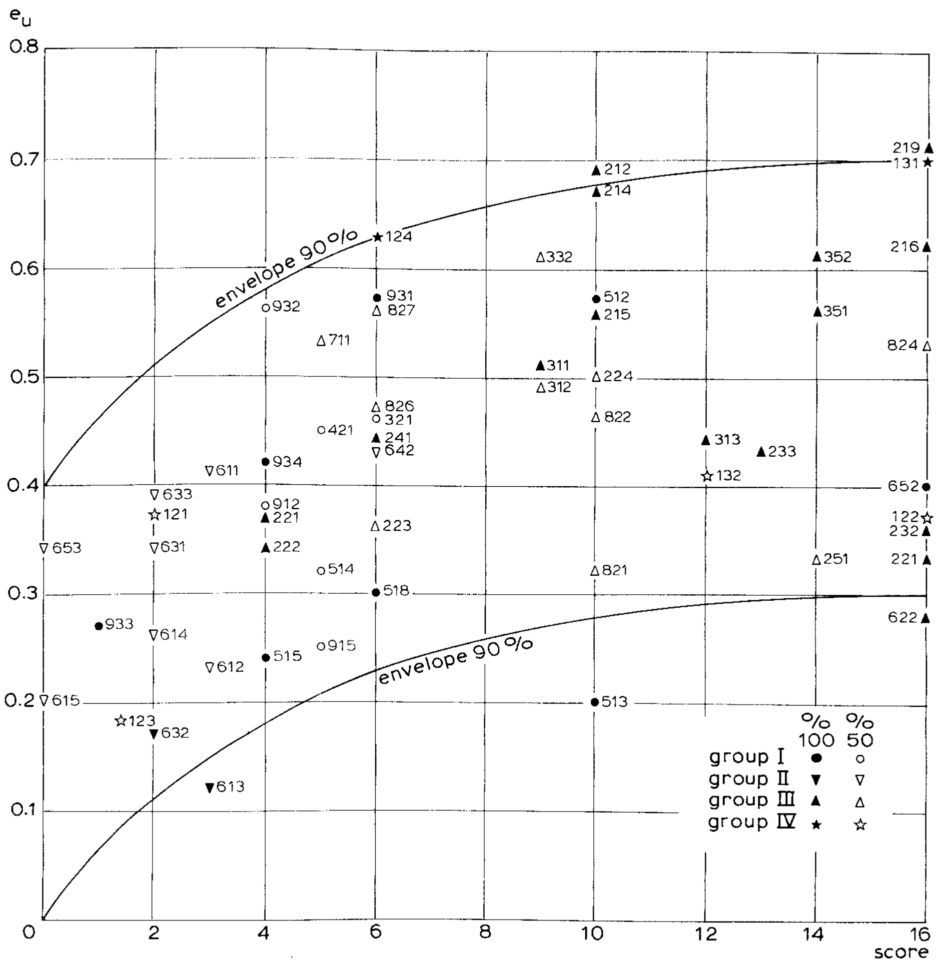

Figure 18 Relation of water charges to tertiary unit efficiency

A study of Figure 18 reveals, for example, that the data points for Group I, II, or III plus IV are not evenly distributed over the figure. There is a significant difference between the average score and the average e_u-value of the various groups, as shown in Table 10.

Table 10 Average score and e_u-values for Group I, II, and III plus IV

Group	Average score	Average e_u-value	Standard deviation, e_u
II	3.6	0.29	0.09
I	6.1	0.39	0.13
III & IV	9.8	0.50	0.13

We can thus conclude that the e_u-value is more influenced by socio-economic conditions in the irrigated area, water use method, irrigation practices, etc., than the often low charges for irrigation water.

The charges paid by the farmers are based on a unit rate per water volume, on cropped area or total area of the farm, or on a combination of these proportional charges and a fixed amount. Table 11, which is based on data from 35 areas, does not indicate any advantage to be gained from any particular method of charging. The very slight differences in efficiencies reveal no tendency towards water economy where cutting down on the farm supply would mean a direct financial gain to the farmer. It would appear that, on the average, direct charges for water use are not considered so particularly high that they constitute an incentive to improve the tertiary unit efficiency. Consequently it is recommended that a system of water charging be used that suits the local conditions and is simple to administer.

Table 11 Average tertiary unit efficiencies with different methods of water charge assessment

	Charges in proportion with	Fixed amount plus charge in proportion with
Water volume	.43	.48
Cropped area	.43	.41
Farm area	.42	.41
e_u average	.42	.42

6.4.3 Relation of tertiary unit efficiency to method of water supply to the farm

From a project management point of view, we can broadly distinguish four methods of water supply to a farm inlet or a group inlet:

A: Continuous supply, with only minor changes in flow rate, generally used in conjunction with basin irrigation (rice). The conveyance system consists of a network of open canals, also flowing at a constant rate;

B: Rotational supply on a pre-determined schedule which depends mainly on the variable crop requirements and the availability of irrigation water at the head works. The schedule of rotational flow is decided by officials of the central irrigation service;

C: Similar to B, but now the schedule of rotational flow is based mainly on water volumes demanded in advance by the individual farmers. The water is conveyed to the farm inlet through a net work of open canals;

D: Water is distributed through a system of pipe lines over the entire project, and farmers can draw water in accordance with their demands of the moment. All (6) questioned projects that have this distribution system use it in conjunction with overhead sprinkler irrigation.

Table 12 shows the average tertiary unit conveyance, and overall efficiencies for these four methods of water supply (see Appendix III, Table I).

Table 12 Average efficiencies for different methods of water supply

Method	No. of samples	e_u	e_c	e_p
A	12	0.27	0.91	0.25
B	20	0.41	0.70	0.29
C	6	0.53	0.53	0.28
D	6	0.70	0.73[1]	0.51

[1] based on two values: .64 and .82

From Table 12 it appears that the tertiary unit efficiency increases sharply from a low value of $e_u = 0.27$ for type A areas to a rather favourable value of $e_u = 0.70$ for type D areas. It also appears, however, that because the management of the conveyance system becomes increasingly complicated, the e_c-value decreases, resulting in very similar project efficiencies for project types A, B, and C. This suggests that the tremendous effort spent on improving the tertiary unit efficiency can easily be nullified by a decreasing conveyance efficiency. To increase the overall project efficiency this problem should be diagnosed so that the increment of e_u at the cost of the e_c can be avoided.

6.5 Irrigation system efficiency

The ultimate goal of any irrigation project is to convey and distribute a quantity of water over the project area and to the fields within it, so that the water can be applied to the crops.

The combined efficiency of water conveyance and distribution is expressed by (see also Section 4.2)

$$e_s = \frac{V_f + V_2 + V_3}{V_c + V_1}$$

If the non-irrigation deliveries from the conveyance system (V_2) and from the distribution system (V_3) are small compared with the volume of water delivered to the fields (V_f), which is usually true, we may write

$$e_s = e_c\, e_d$$

Since $e_s = e_c\, e_d$, those factors that influence e_c and e_d (Sections 6.1 and 6.2 respectively) also have their influence on e_s-values. One combined and one additional factor influencing e_s are dealt with below.

6.5.1 Relation of irrigation system efficiency to actually irrigated area

As was mentioned in Section 6.1, the water conveyance efficiency is a function of the irrigable area, i.e. the area where technical facilities are available for irrigation. Within such an area, however, a part may not be irrigated for some reason or other (see Question A16, Appendix I). This non-irrigated part of the irrigable area does not influence the distribution efficiency, e_d, and since $e_s = e_c\, e_d$, we used the actually irrigated area, i.e. the area which is irrigated at least once a year (Question A15), as the major variable influencing e_s. The relation of the irrigation system efficiency to the actually irrigated area is shown in Figure 19 (see Appendix III, Table A).

For areas with an intermittent supply of water to their farms (Groups I, II, and III), Figure 19 suggests that the optimum size of the actually irrigated area within an organization (project) lies between 3000 and 5000 ha. The upper enveloping curve indicates maximum e_s-values that may be attained on well-managed projects with a modern conveyance and distribution system.

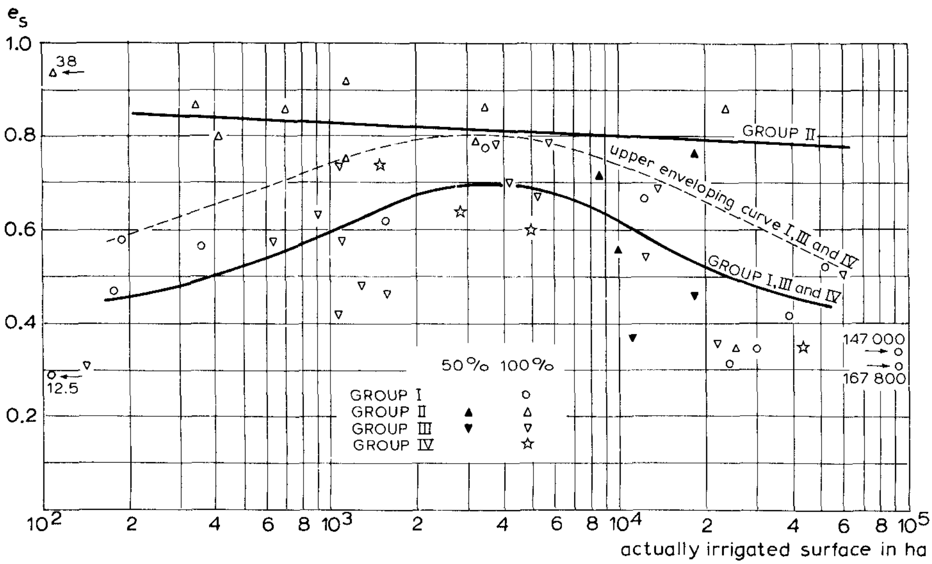

Figure 19 Relation of irrigation system efficiency to average total area which is irrigated at least once per year

Projects which supply water continuously to their farms have a favourable irrigation system efficiency mainly because the system does not require frequent adjustment.

6.5.2 Influence of project management on irrigation system efficiency

From the previous sections the reader will have recognized that good management by a skilled staff is of paramount importance for the efficient operation of an irrigation system. One of the conditions of good management is that the individual farmer should have direct or indirect communication with the organization(s) in charge of the diversion and conveyance of the irrigation supply and of its delivery to the group inlet or farm inlet. The quality of this communication – for example if the farmer has a special request concerning the water delivery to his farm – will influence the efficiency of the irrigation system.

The inquiry allowed four qualifications of communication to be distinguished: adequate, sufficient, insufficient, and poor. Since, in almost all questionnaires, communication was described as 'adequate' or 'sufficient', the average irrigation system efficiencies for these two categories were calculated and are given in Table 13.

Table 13 Relation between average irrigation system efficiency and quality of communication

Group	No. of samples	Communication	
		Adequate	Sufficient
I	13	.48	.41
III	19	.61	.49

Table 13 indicates that if communication is not adequate the irrigation system efficiency decreases, most probably because the irrigation organization does not know how much water has to be supplied at a particular time and place.

The reader will notice from Table J, Appendix III, that practically all organizations that filled out questionnaires qualify the communication as either adequate or sufficient. Taking into account the efficiency values obtained, we assume that the qualification 'insufficient' should have been used several times.

6.6 Overall project efficiency

When an irrigation project is being designed, there will usually be a water source at the upstream end of the project and water-consuming crops at the downstream end, with, in between, a rather dense system of canals, pipelines, ditches, and related structures that serve to convey and distribute the available water over the area.

The water source may take the form of a diversion from a river or it may be a (storage) reservoir. By means of hydrological analysis, the design engineer can find the guaranteed flow at the head works as a function of time.

At farm level the water requirement of the crops is also a function of time, so by applying an average cropping pattern, he can find the water requirement pattern for a unit area.

After the water availability and the water requirement per unit irrigated area have been determined, the design engineer has to decide on the capacity of the canals etc., and, if water is a limiting factor, to what extent the area can be irrigated. A sound decision can only be made if he knows the expected overall efficiency with which the available water will be used. This overall or project efficiency, e_p, is expressed as (see Section 4.2)

$$e_p = \frac{V_m + V_2 + V_3}{V_c + V_1}$$

If the non-irrigation deliveries from the conveyance system (V_2) and from the distribution system (V_3) are small compared with the volume of water needed to maintain the soil moisture at the required level for the crop (V_m), which is usually true, we may write

$$e_p = e_c\, e_d\, e_a = e_c\, e_u = e_s\, e_a$$

Hence all the factors described in the previous sections as influencing the various efficiencies influence e_p too.

7 Practical application of the study results with some examples

In the previous chapter we analyzed the information obtained from questionnaires on 91 irrigated areas throughout the world. As could be expected from such a study, no absolute results were obtained. Instead, certain trends in water utilization efficiencies were revealed as they are related to pre-determined conditions of field irrigation method, size of farms or groups of farms, size of irrigable area, and type of soil in each area.

The question now arises: how can the knowledge gained from this study be put to use? The engineer designing an irrigation system or drawing up a programme of system operation can estimate the different efficiency percentages for the above pre-determined conditions and subsequently make corrections, if necessary, using the relevant tables and diagrams presented in this publication. The corrections to be made refer to the following system conditions: application depth, flow per ha farm plot, delivery period of farm supply, size of rotational unit, canal equipment, water distribution method, and quality of communication.

These corrections will be either positive or negative, depending on the trends indicated in the tables and diagrams, and will sometimes be a matter of the engineer's personal judgement on best system performance with the envisaged canal equipment, water distribution method, and quality of communication.

Figure 20 shows a flow chart of the procedure to be followed in estimating the individual efficiencies so as to arrive at the overall or project efficiency. The procedure will be illustrated by an example, using data from Appendix III.

EXAMPLE 1 (surface irrigation, Area 313)

To estimate the project efficiency of an existing or proposed irrigation project, we must first estimate the efficiencies in the three successive stages of water supply: conveyance, distribution, and field application.

Application efficiency

The efficiency of the third water use stage is largely a function of the application method used in relation to the type of soil, the depth of application, and the flow available to irrigate a unit area farm plot at one single time (Figure 20). The procedure is as follows:

- Initial estimate of e_a

  Table G (Appendix III) shows that Area 313 contains soil types in the following percentages:

silt	silty-clay	clay	heavy-clay
30%	40%	20%	10%

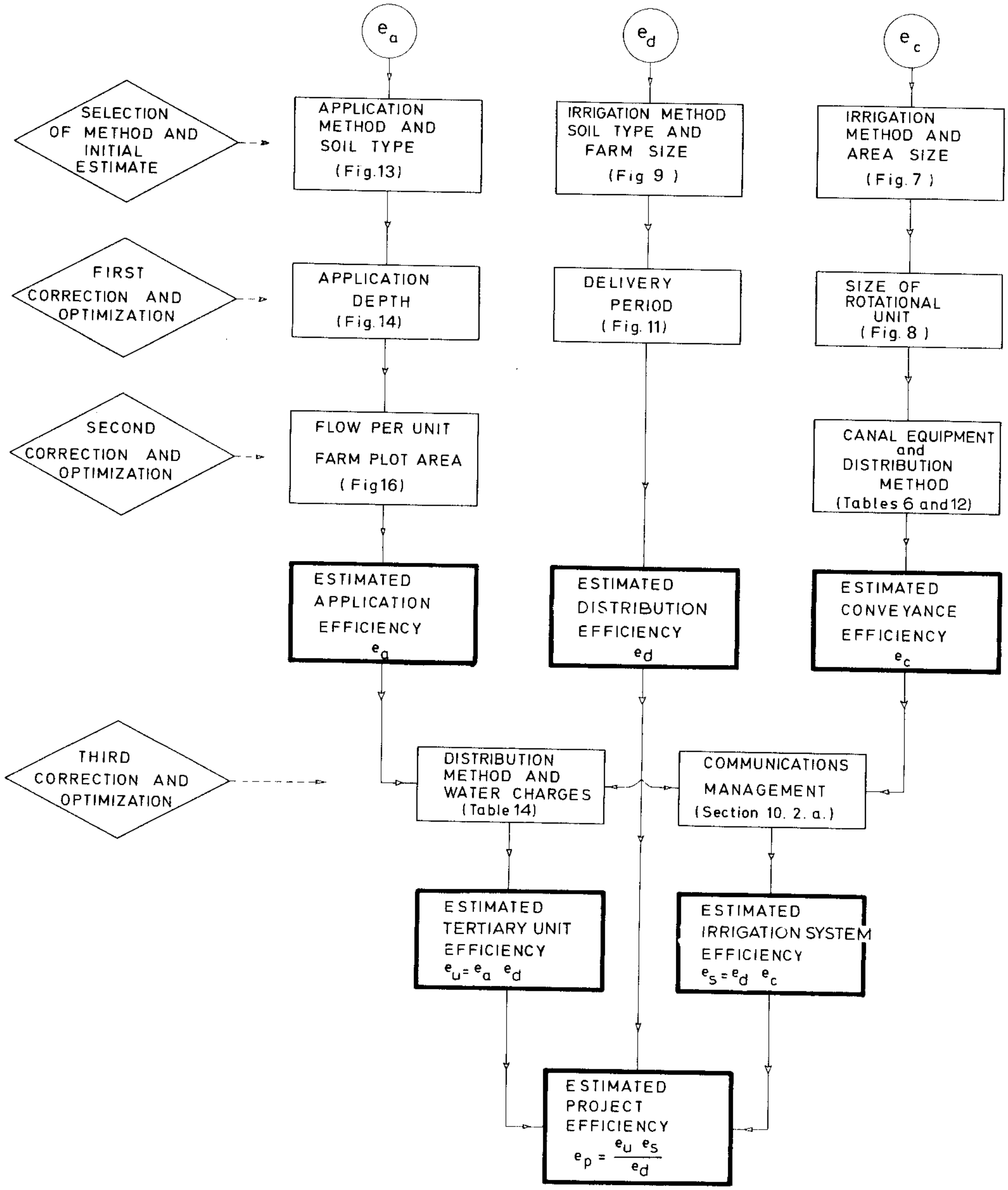

Figure 20 The estimation of efficiencies

The table also shows that 50% of the area is under basin irrigation on rotational supply and that the remaining 50% is furrow irrigated. We assume that the basins are mainly on the relatively flat clayey soils and that the furrows are in silt and silty-clay soils. Using Figure 13 we find that the average initial e_a-value for furrows in silt and silty-clay soils is 0.54 and for basins on clay soils it is 0.58, resulting in a weighted average of 0.56.

- First correction of e_a
  Table D (Appendix III) shows that for Area 313 the average depth of application per irrigation is 60 mm. Figure 14 shows that for an application depth of 60 mm the average e_a-value is 0.54. We now correct the initial estimated value by a ratio 0.54/0.57, where 0.57 equals the average e_a-value for basin and furrow irrigation obtained from Figure 12. The e_a-value after the a first correction is (0.54/0.57) 0.56 = 0.53.
- Second correction of e_a
  Table D (Appendix III) shows that the average size of a farm plot in Area 313 is 0.87 ha and that 10 l/s is available to irrigate such a plot. This corresponds to 10/0.87 = 11.5 l/s per ha plot. Figure 16 shows the average e_a-value corresponding to this unit discharge to be 0.55, so that the corrected e_a-value equals (0.55/0.57) 0.53 = 0.51. This value is our estimate of the application efficiency.

Distribution efficiency
The efficiency of the second water use stage depends largely on the irrigation method, soil type, whether farm ditches are lined or not, average farm size, and the average duration of water delivery to a farm.

- Initial estimate of e_d
  From Tables D and G (Appendix III) we obtain information on the soil types in the area and see that the average farm size is 2.3 ha. Area 313 irrigates on a rotational system, and farms in the area have earthen ditches. With this information and Figure 9 we find as an initial estimate that e_d equals 0.78. The reader will note that to allow for the dominant soil type we selected a value about midway between the upper envelope and the average curve. If all farm canals were lined or if the dominant soil type were clay to heavy clay, an e_d-value of 0.86 would be selected. On the other hand, if sand were the dominant soil type, 0.52 would be our initial estimate.
- First correction of e_d
  Table D (Appendix III) shows that the average duration of water delivery to a farm in Area 313 is 35 hours. Figure 11 shows that the average e_d-value for such a period is 0.73. Since farm size and duration of flow at the farm inlet are not independent of each other, we obtain our final estimate of e_d by averaging our initial estimate and the value found after correction. Hence $e_d = (0.78 + 0.73)/2 = 0.76$.
  If the farm canals had been lined or if pipe lines had been used as a (farm) distribution system, we would have taken 0.88 as first correction value, which equals the average e_d-value for farms having a water delivery of 7 days or more.

Conveyance efficiency
The efficiency of the first water use stage is mainly a function of the irrigation method, size of the irrigable area, size of a rotational unit, and the method of water supply.

- Initial estimate of e_c
  Table A (Appendix III) shows that the irrigable surface of Area 313 is 1000 ha. For areas of this size and having rotational flow, we find on the curve from Figure 7 an initial estimate of $e_c = 0.82$.
- First correction e_c
  Table B (Appendix III) shows that the size of a rotational unit in Area 313 varies between 100 and 200 ha. Taking an average size of 150 ha we find from Figure 8 an average e_c-value of 0.87. We now correct the initial estimated value by the ratio 0.87/0.73, where 0.73 equals the average of all e_c-values shown in Table 2. Our midway value becomes $(0.87/0.73)0.82 = 0.98$.[1]
- Second correction of e_c
  The method under which water is supplied to the farms (rotational schedule, continuous supply, etc.) has a dominant influence on the conveyance efficiency. The methods distinguished in Section 6.4.3 have average e_c-values which differ markedly from one another (see Table 12).
  Table C and I (Appendix III) show that Area 313 has a rotational supply on a predetermined schedule and has the proper structures in its (earthen) canals to operate such a schedule. According to Table 12, the average e_c-value for areas with this distribution method is 0.70. The second correction on e_c is made by averaging the end-value after the first correction and the value obtained from Table 12, resulting in a final estimated e_c-value of $(0.98 + 0.70)/2 = 0.84$.

Tertiary unit efficiency
Tertiary unit efficiency is the product of the field application and the distribution efficiencies plus a minor correction for the water charges the farmer has to pay.
In Section 6.4.2, we introduced a 'score', which may be used as a criterion for the value to be added to the product of the estimated e_a- and e_d- values as shown in Table 14.
Table H (Appendix III) shows that Area 313 scored 12. The final estimate of the tertiary unit efficiency thus equals $e_a \times e_d$ + correction $= 0.51 \times 0.76 + 0 = 0.39$.

Table 14 Correction on e_u based on water charge score (see also Section 6.4.2)

Score	0	2	4	6	8	10	12	14	16
Value to be added to estimate e_u	−0.03	−0.03	−0.02	−0.01	0	0	0	+0.01	+0.02

Irrigation system efficiency
The irrigation system efficiency is the product of the distribution and conveyance efficiencies, or $0.76 \times 0.84 = 0.64$.
For irrigated areas operating under average conditions, no additional correction for management and communication is required since in our estimate of e_c the problem

[1] This midway value sometimes becomes greater than unity. It has no physical meaning and serves only as a mathematical value

related to management and communication has already been taken into account. Only if the project management is hindered or disrupted by outside factors is a negative correction on e_s (or even on e_c) required.

Project efficiency
The overall or project efficiency equals

$$e_p = e_c\, e_d\, e_a$$

or

$$e_p = \frac{e_u\, e_s}{e_d}$$

Our final estimate of the project efficiency for Area 313 is
$(0.39 \times 0.64)/0.76 = 0.33$.

EXAMPLE 2 (basins with continuous supply)

Since many of the factors influencing surface irrigation are not relevant in areas where rice is grown in basins and where the water supply is continuous, we give Area 653 as a second example.

Application efficiency

- Estimate of e_a
  Table A (Appendix III) shows that the dominant soil type in the area is clay and that the only application method is basins with continuous supply. From Figure 13 we find an estimated e_a of 0.45. Since the depth per application and the flow per unit plot area play no role, this value is also our final estimate of e_a.

Distribution efficiency

- Estimate of e_d
  Table E (Appendix III) shows that the average farm size in Area 653 is 0.85 ha. For this size we find from Figure 9 that e_d is 0.95. This value is somewhat above the average since the ditches are excavated in clay. For continuous supply, the delivery period is irrelevant and thus our final estimate of e_d is 0.95.

Conveyance efficiency

- Estimate of e_c
  Table A shows that the irrigable area is 38 ha. From Figure 7 we find 0.96 as an initial estimate of e_c. The size of a rotational unit plays no role. The area has a distribution method of Type A (Table 12) with an average e_c of 0.91. Our final estimate is $(0.96 + 0.91)/2 = 0.94$.

Tertiary unit efficiency
The water charge score for Area 653 is zero, so that our estimate of $e_u = e_a\, e_d - 0.03 = 0.45 \times 0.95 - 0.03 = 0.40$.

Photo 10 Properly levelled fields, a lined distribution system, and skilful operation and management of the irrigation system ensure a high efficiency of water use

Irrigation system efficiency

Our estimate of the irrigation system efficiency equals the product of e_d and e_c, and is 0.89.

Project efficiency

Our estimate of the project efficiency is

$$e_p = \frac{e_u\, e_s}{e_d} = \frac{0.40 \times 0.89}{0.95} = 0.37$$

8 Evaluation of the applied approach

By using Figure 20 and applying the approach described in Chapter 7, we estimated the various efficiencies of all those areas from which a fully completed questionnaire had been received. The estimated efficiency values and the calculated values from Table 2 were plotted against each other in Figure 21.
As can be seen from these diagrams, a fair correlation exists between the calculated efficiencies and those estimated by the method we used in combining the various factors. Several other methods of combining the factors that influence the water use efficiency were tested but the method described gave the best results.

We recommend the use of this approach in estimating the various water use efficiencies for:
- Evaluating the water utilization efficiency on existing projects and finding methods to improve system conditions or even optimize them;
- Making a proper estimate of the water use efficiency when considering the various alternatives for a future irrigation project.

EFFICIENCY VALUES TAKEN FROM TABLE 2

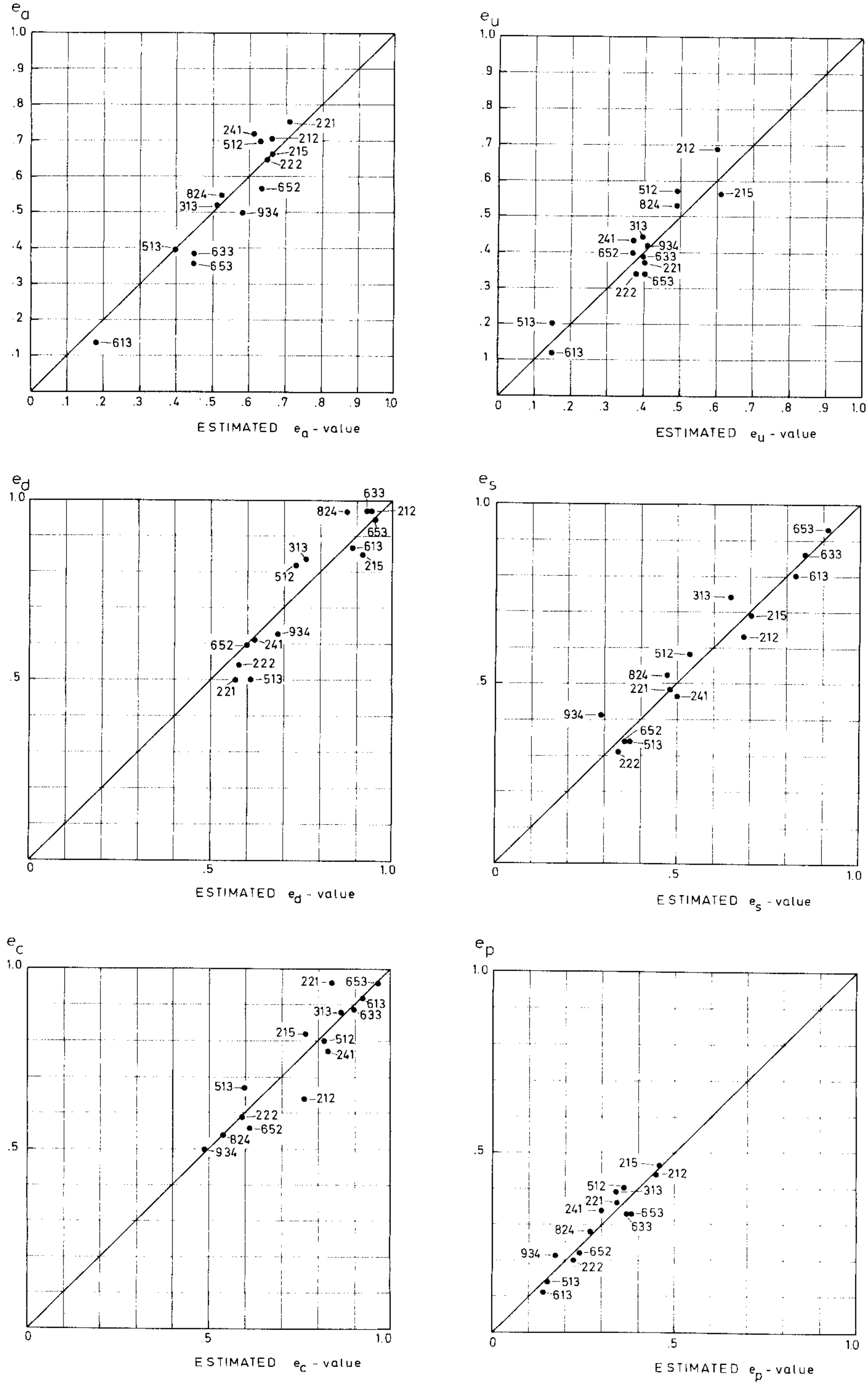

Figure 21 Correlation of estimated and calculated efficiency values

9 Conclusions and recommendations

1. To estimate the efficiency of water use in existing or future irrigation projects, the method described in this publication has proved very suitable. It consists of estimating separately the application, distribution, conveyance, tertiary unit and irrigation system efficiencies which, combined, give the project efficiency (Figure 20). An important aspect of the method is that it indicates steps that can be taken to improve system conditions or even to optimize them.

2. In an irrigable area where the entire canal and ditch system operates at a near constant flow rate so that no division structures have to be manipulated, the only water losses will be due to seepage. Such a system is usually applied in areas where rice as sole crop is cultivated in basins with a continuous water supply. In such areas the conveyance efficiency decreases slightly as the irrigable area increases (Group II, Figure 7).

3. In all irrigated areas where either one main crop (other than rice) or a certain combination of crops is cultivated, the water supply must be adjusted, sometimes even frequently (Groups I, III, and IV). A conveyance efficiency with an average of about 0.88 can be attained if the size of the irrigable area is between approximately 4000 and 6000 ha (Figure 7).
   For smaller areas the conveyance efficiencies decrease significantly, probably because of difficulties encountered by the project management in making the rather frequently needed adjustments in the discharge measuring/regulating structures in the relatively small-capacity canals; moreover, small areas are less likely to be managed by an adequate operational staff. If the area served by one canal system is larger than about 10000 ha, the conveyance efficiency also decreases significantly. The reason for this is that the project management apparently faces the problem of controlling the water supply and is not able to balance the specific requirements of the various sub-areas. To this can be added that there is little flexibility in adjusting the water supply in extensive irrigation systems with a relatively long travel time for water. Here an adequate communication system and automatic controls are of primary importance.

4. To achieve a favourable water conveyance efficiency in large irrigation projects, it is recommended that the projects be managed as follows:
   a) General Project Management
      The general project management operates the dam-site or diversion and the main canal. The main canal should have a flow rate that can be adjusted to meet the water requirements of the various lateral units;
   b) Local Irrigation Management
      Depending on topography and local conditions, the irrigation project should be divided into a number of lateral units, each having an area of between 2000 and 6000 ha (mean 4000 ha). Each lateral unit should receive its water at one

point from the main canal and should have its own skilled local irrigation management staff who will be responsible for the water supply within that lateral unit only.

5. From the viewpoint of conveyance efficiency, the optimum size of a rotational unit (i.e. an irrigated unit commanded by a canal on intermittent flow) lies between 70 and 300 ha (Figure 8).

6. We would further recommend that the main, lateral, and sublateral canals be operated on a schedule of continuous flow and that the area not be divided into subrotational units. During the entire season the flow rate in each of these canals may vary with the water requirement of the commanded area.

Each lateral unit should contain a number of rotational units whose size should be between 70 and 300 ha, depending on topography and local farm size. Within each rotational unit, the water distribution should be organized independently of the overall conveyance and should be based on the requirements of the farms in that unit.

10 References

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Appendix I
Example of a completed questionnaire

INTERNATIONAL COMMISSION ON IRRIGATION AND DRAINAGE
48, Nyaya Marg, Chanakyapuri, New Delhi-21 (India)

QUESTIONNAIRE ON METHODS OF WATER DISTRIBUTION FOR SMALL FARM UNITS

Introduction

The general aim of this inquiry is to obtain information which will result in general indications, trends and possible positive conclusions regarding the various methods of distributing water to, and on, the farms under various physical, technical and sociological conditions.

The questionnaire has been tested in nearly ten Member Countries and results obtained have led to the preparation of the enclosed final edition. On basis of the results of the test enquiry, the International Executive Council of I.C.I.D., at its meeting held in Ankara in June last, unanimously agreed to the collection of data on a world-wide scale by means of the questionnaire.

It may be important to note that the results of the enquiry will be presented without any indication of country, project or official involved. The data will be anonymous and processing will only be based on the facts indicated in the forms.

The questionnaire to be filled out consists of a set of forms of 15 pages for each specific irrigation area. It is divided into the following parts :

—A. General information	sheets 1— 2	questions A.1—A.25
—B. Water distribution	sheets 3— 6	questions B.1—B.19
—C. Agriculture	sheets 7—13	questions C.1—C.44
—D. Evaluation	sheets 14—15	questions D.1—D.6

A general explanation is given in the following paragraphs. It is recommended to read this explanation before starting the filling out the forms. The definitions on which the terminology has been based are also added.

It would be appreciated if the forms, duly completed, are returned to the, following address *before January 31, 1972*, under intimation to the Central Office of the ICID :

International Institute for Land Reclamation and Improvement
P.O.B. 45, Wageningen
THE NETHERLANDS

General information

1. The inquiry is intended *for areas where irrigated farm units of less than 10 to 15 ha (25 to 37.5 acres) prevail*, and where each farmer is personally involved in the irrigation of his land. If in a certain area farms of this size are intermixed with farms larger than the indicated limit, it is requested to include all farm types in the area in one set of forms.
2. The questionnaire has been designed to refer to an irrigated area, where the technical and agricultural conditions can be deemed to be of a uniform character. The extent of the area to be covered under one set of forms is, therefore, not limited to a maximum, although it will often be convenient to restrict the data on one set to those related to an area supplied by one important river diversion. Areas of less than 500 to 1,000 ha (1,250 to 2,500 acres) are usually too small to be of great interest for the inquiry, unless such small areas represent important features applicable on a larger scale.
3. In case an irrigated area comprises a very large geographic unit, wherein no specific variations occur in the technical or agricultural conditions, it is recommended that, in order to save time in collecting the information, one set of forms be prepared for an area, for example of 100,000 ha (250,000 acres), which can be considered representative for the entire unit. It will be appreciated if in such case an indication is placed on Form no 1 to that effect.
4. The total number of sets of forms to be filled in for one country depends on the magnitude of the irrigated surface in that country and on the variations in the natural conditions, in the agricultural and sociological situation, and in the technical standards. Generally, therefore, it can be stated that areas of different climatological conditions, or of different agricultural patterns, or where the irrigation systems have been constructed at different stages of the technical development, cannot be included in the same set of forms.
5. The information requested in the various questions on the forms can usually be supplied by selecting the appropriate alternative indicated

at the right hand side and by marking this alternative by (X). In cases where more than one of the given alternatives apply, each of these should be marked by (X), and if considered necessary, the sequence of importance of the applicable alternatives can be indicated by X.1, X.2, X.3, etc.

If the indicated alternatives do not apply, or if an alternative described as "other method", "other purpose" etc., is selected, please give the pertinent information under the heading "Further information" at the end of the relevant section of the questionnaire.

6. For some of the questions the information should be given in figures, such as the precipitation, extent of the area. This kind of information can be expressed either in metric units or in the British-American units as indicated at the relevant lines. It is requested to strike out in each case the non-applicable units.

It will be appreciated if the water charges referred to in question C.28 are expressed in the country's own currency, while mentioning on Form no 1 the rate of exchange with the U.S. $ of that currency at the time of filling in the forms.

7. Questions, which obviously do not apply to the area under consideration, should be passed over under marking these at the right hand side of the form by (000).

If it is felt that certain aspects in the area, or special data, which are essential for a full understanding of the water distribution, are not sufficiently covered by the questions, it will be appreciated if such information is added under "Further information" at the end of the relevant section of the questionnaire.

8. If certain information or figures, supplied on the forms, are not based on exact knowledge or data, but are derived from an appraisal, it is requested to note this by adding "appr" to the information or figures.

Terminology

In the questions on the forms the terminology is based on the following definitions :

main canal : a canal forming part of the primary conveyance system, serving the various sub-areas of an irrigated area.

lateral canal or lateral : a secondary canal taking off directly from (one of) the main canal (s) and delivering to sub-laterals and/or group inlets or farm inlets.

sub-lateral : a canal forming part of the secondary conveyance system and delivering to group inlets or farm inlets.

group inlet : a collective inlet supplying an area wherein a number of individual farms, or a number of individual (farm) plots, are located.

distributary : a ditch, forming part of the tertiary conveyance system and delivering to individual farms or individual (farm) plots.

farm inlet : an inlet supplying a piece of land belonging to one individual farm.

farm ditch : a ditch within the boundaries of an individual farm or individual (farm) plot.

The above technical definitions may sometimes still leave room for doubt, as, *e.g.*, whether a certain category of canals should be classified as sub-lateral or as distributary. In such cases it is recommended to take into consideration the organisational set-up of the water distribution, in particular to pay attention to the question where the control of the water is turned over from the overall distributing organisation to the individual or collective water-users. This point of delivery will be located immediately upstream or downstream of the farm inlet, if the farm receives its supply directly from the secondary canals under the control of the overall distributing organisation. In case the overall distributing organisation delivers the supply to a group of farms, the point of delivering is immediately upstream or downstream of a group inlet, while the distributaries convey the water from this point to the farm inlets.

SERIAL NO. 4 SHEET 1

A. GENERAL INFORMATION

1. Country (National I.C.I.D. Committee).	1. CODE 934
2. State, province or district.	2.
3. Name of area, subdistrict or project.	3.
4. Serial No. of this questionnaire. Total number of sets of forms submitted by the National Committee.	4. Serial No. 4 Total number of sets 4
5. Rate of exchange of local currency ?	5. U.S. $1 =
6. Name(s) of the organisation(s) entrusted with the supply of the information.	6. CODE 934
7. Date of submission of the information.	7. April 1971

8. What is (are) the main agricultural crop(s) in the area ?

8.	cereals others than rice	rice	fodder	cotton	sugar cane	fruits	pastures	vege-tables	palm trees	other crops
crops	36.3 %			40 %		0.03 %		23.6 %		0.07 %

9. What is the total gross area considered under the present set of forms ? (surface either in ha or acres)	9. gross : 139 835 ha/~~acres~~
10. What is the total cultivable surface (physically suitable for agriculture) within the indicated gross area ?	10. Cultivable : 97 000 ha/~~acres~~
11. What is the balance of non-cultivable land ?	11. Balance : 42 835 ha/~~acres~~

12. Is (part of) the balance of non-cultivable land of question 11 utilised for non-agricultural purposes and if so, for what purpose(s) ?

12. Balance	towns villages	canals	roads	industry	other purposes
Utilised for non-agricultural purposes	X1	X3	X2		

13. What is the total irrigable area (area where the technical facilities are available for irrigation) within the gross area indicated under 9 ?	13. Irrigable : 38 512 ha/~~acres~~
14. What is the average total area which is irrigated at least once a year ?	14. Irrigated : 38 512 ha/~~acres~~
15. What is the balance (area which is not irrigated in an average year) ?	15. Balance : — ha/~~acres~~

16. For what reason(s) is this balance not irrigated ?

16. not irrigated because of

lack of irrigation installation	lack of drainage	water deficiency	sufficient rainfall for one crop	annual fallow	economic reasons	other reasons

000

17. Is the area covered on this set of forms representative of a larger area, and if so, what is the extent of this larger area ?

17. The area is representative for a larger area

No	Yes
X	

Extent of larger area, if any ______ ha/acres

A. GENERAL INFORMATION (*continued*)

SERIAL NO...4 SHEET 2

18. At what (approx.) time has agriculture commenced in the area?
19. At what (approx.) time has irrigation commenced in the area?

	ancient times	from 100 to 50 years ago	from 50 to 15 years ago	within the last 15 years
18. Commencement of agriculture	X			
19. Commencement of irrigation	X2	X1		

20. Have any major changes occurred in the area within the last 15 years, and if so, did this happen because the area formed part of a development project?

20. Major changes

No major changes	major changes	
	area in a project	area not in a project
	X	

21. Can the major changes in the area, as indicated in question 20, mainly be attributed to one or several of the following causes ?

21. Causes of changes

improved irrigation	improved drainage	cropping practices	cultural practices	tenure structure	composition or density of population	other causes
X1	X2		X3			

22. What organisation(s) and/or persons control the supply of the irrigation water to the area and the delivery to the farm units?

22. Control by organisations & persons

government organisation	special authority	private enterprise	co-operative	land-owners
X				

groups of farmers	individual cultivator

23. Please, can you add a copy of any publication(s) related to the area under consideration, or refer to the titles of any such publications?

23. Enclosed publications : __________

Reference to publications : Code 934

24. Please, can you supply any maps of the main irrigation system and of a sample of the detailed layout of the distribution system?

24. Enclosed maps : Map of canal system

25. Further information

B. WATER DISTRIBUTION

1. **Is the irrigation water supplied from surface- or ground-water resources, or from both?**

1. Supply	Surface water	Surface & ground water	Ground water
	X		

2. **If the area, partly or entirely, is supplied with surface water, is the flow then** diverted at one site or at several sites, and is (are) the diversion(s) by gravity or by pumping?

2. Diversion	one site	several sites
by gravity		X
by pumping		

3. Do any storage reservoirs exist for the surface-and/or ground water supply and if so, is this storage mainly for daily, seasonal, or carry-over (annual) storage?

3. Storage	no storage reservoirs	daily storage	seasonal storage	carry-over storage
surface water			X	
ground water				

4. **Is the flow in the irrigation canals generally regulated, and if so, by what means does the regulation take place?**

4. Regulation					
No regulation	Regulation by :				
	temporary controls	fixed controls	movable gates (not automatic)	automatic devices	other devices
			X		

5. **Is the water mainly conveyed from the diversion site, or the wells, to the farms by earthern canals, lined canals, chutes, or pipelines?**

5. Conveyance	earthen canals	lined canals	chutes	pipelines
main canal (s)	X1	X2		
laterals	X1	X2		
sub-laterals	X			
distributaries	X			

6. Is the flow to the fields, entirely or partly, lifted at one or more points by means of pumps or by other means?

6. lift	not lifted	partly lifted	entirely lifted
		X	

7. Is the flow in the main irrigation canals, the laterals and the sub-laterals, continuous or intermittent during the irrigation season, and, in the latter case, on what general schedule are these canals operated?

7. operation	main-canal (s)	lateral	sublateral
continuous flow			
intermittent flow	X	X	X

schedule of intermittent flow: on demand

B. **WATER DISTRIBUTION** *(continued)*

SERIAL NO. 4 SHEET 4

8. What is in each month the average total discharge for the supply of the entire area?

9. What surface is actually irrigated in each month?

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
8. Discharge	27.3	34.3	34.4	32.6	33.3	38.8	38.2	34.5	25.3	17.1	17.8	24.9	m³/sec ~~cusec~~
9. Surface	20.3	23.1	25.6	23.5	24.8	27.9	28.4	25.7	18.2	12.7	12.8	18.5	× 1000 ha/~~acres~~

10. Which of the following organisations, and/or individuals, operate the main canal(s), the laterals, the sub-laterals, the group inlets, the distributaries and the farm inlets?

10. Operation by	central irrigation organisation	by a special distribution organisation	by a specially assigned official	by a group of farmers
main canals	X			
laterals	X			
sub-laterals	X			
group inlets	X			
distributaries	X			
farm inlets	X			

	by an individual farmer	by other organisations or persons
main canals		
laterals		
sub-laterals		
group inlets		
distributaries		
farm inlets		

11. Is the flow in the lateral canals delivered to sub-laterals, to group inlets, or to farm inlets?

12. Is the flow in the sub-laterals delivered to group inlets or to farm inlets?

11. Delivered to	sub-laterals	group inlets	farm inlets
from lateral	X	X	X
12. from sub-lateral		X	X

13. Is the flow through the group inlets, in the distributaries, and through the farm inlets continuous or intermittent during the irrigation season, and in the latter case, on what general schedule are these structures and canals operated? (In case no general schedule for intermittent flow exists, please give an example of the intermittent flow pattern for a specific period of time).

13.	group inlets	distributaries	farm inlets
continuous flow			
intermittent flow	X	X	X

schedule of intermittent flow: on demand

B. WATER DISTRIBUTION *(continued)*

14. Is the water surface level in the laterals, the sub-laterals, the distributaries and the farm ditches controlled by means of check structures at the points where the flow is turned out to sub-laterals, group-inlets, farm-inlets, or field-ditches, and if so, what type of control check is used?

14. Control of water surface level

	No control of water level	control of water level by: temporary means	fixed check structure	adjustable check structure
laterals			X	
sub-laterals			X	
distributaries			X	
farm-ditches			X	

15. Of what order is the average area served by one lateral, one sub-lateral, one group-inlet and one farm inlet?

15. Average area

ha	>5000	1000-5000	500-1000	200-500	100-200	50-100	10-50	5-10	1-5	<1	ha
acres	>12500	2500-12500	1250-2500	500-1250	250-500	125-250	25-125	12.5-25	2.5-12.5	<2.5	acres
lateral		X									
sub-lateral				X							
group inlet						X					
farm inlet									X		

16. If the flow in the laterals or in the sub-laterals is delivered to group inlets serving a certain number of individuals farms (or farm plots):

(*a*) How many of these individual farms (or farm plots) are served generally by one group inlet?

16. Group inlets

	> 500	100-500	25-100	5-25	< 5
(*a*) number of farms				X	

(*b*) Have these individual farms (or farm plots) each a farm inlet?

	No farm inlet for each farm	Farm inlet for each farm
(*b*) farm inlets	X	

(*c*) Is the flow through the group inlet usually delivered simultaneously to all farms (or farm plots), or to a certain portion thereof, or to a single farm or farm plot?

	all farms or plots	> 50% of all farms or plots	10—50% of all farms or plots	<10% of all farms or plots	1 farm or farm plot
(*c*) simultaneously delivered to:					X

17. How many managers, engineers, technicians, overseers, watermasters, ditchriders, gatesmen and watchmen are on the staff of, or employed in, the area by each of the following organisations?

17. Staff of organisation	central irrigation organisation	special distribution organisation	specially assigned officials	group of farms	co-operative (s)	other organisation(s)
managers	1					
engineers	5					
technicians	2					
overseers	9					
watermasters	4					
ditchriders	53					
gatesmen	7					
watchmen	8					

18. If any water charges are levied in the area, do these charges cover partly, or entirely, the annual costs connected with ?

(*a*) the operation of the irrigation system.

(*b*) and if these operation costs are completely covered by the water charges, do these also cover, partly or entirely, the annual costs of maintenance of the irrigation system ?

(*c*) and if both operation and maintenance costs are completely covered by the water charges, do these water charges also cover, partly or entirely, the annual costs of amortization and interest (if any) of the capital invested in the irrigation system ?

18. Water charges	coverage by water charges			
	none	0-50%	50-100%	complete
(*a*) operation costs			X	
(*b*) in addition maintenance costs			X	
(*c*) in addition capital costs	X			

19. Further information?

C. AGRICULTURE

SERIAL NO. 4 SHEET 7

1. Please indicate:
   - —by horizontal lines the growing season of each of the main crops and the diversified crops (if any).
   - —the approximate percentage of the total cultivable area wherein each of the main crops and the diversified crops are cultivated.
   - —the average monthly consumptive use for each of these crops.
   - —the average monthly irrigation field application for each of these crops.

1. Crop	% of area	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	
No. 1 ALFALFA growing season	13.1													
consumptive use		25	34	66	93	124	142	158	164	151	139	114	98	mm/~~inches~~ per month
field application		45	60	115	169	218	250	277	287	265	243	200	172	mm/~~inches~~
No. 2. CORN growing season	32.1													
consumptive use				43	91	148	168	154	108					mm/~~inches~~ per month
field application				75	160	260	295	270	189					mm/~~inches~~
No. 3 WHEAT and BARLEY growing season	15.7													
consumptive use		102	132	150	87								46	mm/~~inches~~ per month
field application		179	232	263	153								82	mm/~~inches~~
No. 4. TOMATO growing season	3.7													
consumptive use				37	79	29	146	138	101					mm/~~inches~~ per month
field application				65	138	226	256	243	177					mm/~~inches~~
Diversified Crops FOR. OATS growing season	16.4													
average consumptive use		100									130	70	100	mm/~~inches~~ per month
average field application		75									228	123	175	mm/~~inches~~
2. Monthly precipitation														mm/~~inches~~
3. Monthly volume farm type A		94	94	120	110	110	90	104	110	74	84	86	99	m^3/ha or ~~acre-ft/acre~~
farm type B		94	94	120	110	110	90	104	110	74	84	86	99	
farm type C														

2. What is the average monthly precipitation in the area?

3. What is the mean monthly volume of irrigation supply delivered at the farm inlets of the different farm types (in m^3/ha or acre-feet/acre) (for different farm types see question 4 of this section).

4. What is the average size of a typical farm (or the sizes of various typical farms) predominant in the area, and what is the average surface of the typical farm(s) annually cultivated with each of the crops indicated under question C.1.?

4. Average farm size and crop surface	average farm size	main crop No. 1	main crop No. 2	main crop No. 3	main crop No. 4	diversified crops	
farm type A	1.2						ha/~~acres~~
farm type B	3.4						ha/~~acres~~
farm type C	—						ha/acres

one crop per farm

C. AGRICULTURE (*continued*)

5. Does (Do) the typical farm(s) consist of a single plot of land, or does (do) the farm(s) contain several plots, and if so, what is the average size (approx.) of each of these plots? What is the total area occupied by all farms of one farm type together?

5.	farm type A	farm type B	farm type C	
single plot	X	X		
several plots				
approx. average size of each plot	1.2	3.4		ha/~~acres~~
total surface occupied by farm type	–	–		ha/acres

6. Can the typical farm(s) be considered as a family farm without hired labour, or as a family farm with hired labour, or is the bulk of the work carried out by hired labour?

6.	farm type A	farm type B	farm type C
family farm *without* labour	X		
family farm *with* hired labour		X	
work mainly *by* hired labour			

7. Does the farmer dispose of the same land permanently (at least 5 years), or is all or part of his land temporarily allocated to him (for less than 5 years)?

7.	farm type A	farm type B	farm type C
permanent disposal		X	
temporary allocation	X	X	

8. Which percentage of the typical farm(s) is fallow for at least one year, and is this fallow caused by water deficiency, insufficient drainage, soil fertility, salinity or alkalinity, cultural practices, available labour, or for other reasons?

8.	farm type A	farm type B	farm type C	
percentage of fallow caused by :				% 000
water deficiency				
insufficient drainage				
soil fertility				
salinity or alkalinity				
cultural practices				
available labour				
others reasons				

9. What is the average size of the household (family plus resident dependents)?

9.	farm type A	farm type B	farm type C	
size of household				persons 000

the farmers live in villages

10. Is usually any cattle kept on the farm, and if so, is this mainly done for the production of meat or dairy, or for traction or for other reasons?

10.	farm type A	farm type B	farm type C
No cattle			
cattle for meat	X	X	
cattle for dairy	X	X	
cattle for traction			
cattle for other reasons	X	X	

C. AGRICULTURE *(continued)* SERIAL NO. 4 SHEET 9

11. Is the purpose of the farming mainly aimed at subsistence, or at marketing, or at both?

11. Purpose			
subsistence			
marketing			
subsistence and marketing	X	X	

12. Which farm activities are usually mechanised?

12.			
No mechanisation			
Mechanised land preparation	X	X	
sowing	X	X	
weeding	X	X	
harvesting	X	X	

13. Does the farmer usually have other employment outside his farm work?

13. Outside employment	farm type A	farm type B	farm type C

000

14. Which crops are irrigated continuously, and which are irrigated intermittently?
What are the field irrigation methods generally applied for the various crops and diversified crops?

contin-uous	inter-mittent	irrigation methods	on flat land: basin irrigation	on flat land: furrow patterns	on sloping land: wild flooding	on sloping land: borders	on sloping land: straight furrows	sub-surface irrigation	sprinkler irrigation	other methods
	X	main crop No. 1	X			X				
	X	main crop No. 2		X			X			
	X	main crop No. 3	X			X				
	X	main crop No. 4		X						
	X	diversified crops		X		X	X			

15. What is for each of the farm types the size of flow at the farm inlet?

16. What is the average delivery time per irrigation turn at the farm inlet for each of the farm types (for intermittent irrigation only) in hours?

	farm type A	farm type B	farm type C	
15. Size of flow at farm inlet	100	100		l/sec. or ~~cusec~~
16. Average delivery time at farm inlet	7	19		hours

17. How many irrigation turns per month does each farm type have during the different months of the growing season (for intermittent irrigation only)?

17. Number of irrigation turns per month

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
farm type A	1	1	1	2	2	1	1	1	1	1	1	1
farm type B	1	1		2	2		1	1	1	1	1	1
farm type C												

C. AGRICULTURE *(continued)*

18. How can the surface soil and the substratum (sub-soil) for the various crops generally be characterised?

19. Does any salinity or alkalinity occur in the soil?

20. If salinity occurs in the soil, is this slightly, moderately, or severe saline?
salinity problems are minimal

21. If the soil is affected by alkalinity, is it slightly, moderately, or strongly affected?
alkalinity problems are minimal

surface soil	sand X		loam		silt		silty clay		clay		heavy clay		
substratum	light text.	heavy text.	light text.	heavy text.	light text	heavy text.	light text.	heavy text.	light text.	heavy text.	light text.	heavy text.	
18. main crop No. 1			X1	X2	X3	X4	X5	X6	X7	X8			
main crop No. 2			X1	X2	X3	X4	X5	X6	X7	X8			
main crop No. 3			X1	X2	X3	X4	X5	X6	X7	X8			
main crop No. 4					X1	X2	X3	X4	X5	X6			
diversified crops			X1	X2	X3	X4	X5	X6	X7	X8			
19. salinity							X5	X4	X3	X2	X1		
alkalinity							X5	X4	X3	X2	X1		total:ha
20. salinity: slight					X6	X5	X4	X3	X2	X1			400
moderate					X6	X5	X4	X3	X2	X1			600
severe					X6	X5	X4	X3	X2	X1			200
21. alkalinity slight							X5	X4	X3	X2	X1		35
moderate								X4	X3	X2	X1		40
strong								X3		X2	X1		280

22. Is the ground-water table within measurable distance from the surface, and if so, what is the average depth of the ground-water table below the surface? (to supply the information for the various soils).

23. If the ground-water table fluctuates annually, what is approximately the annual fluctuation for the various soils indicated in 22?

24. Is the ground water non-saline, slightly saline, moderately saline, or strongly saline in the various soils?

25. **What is the average depth of field application per irrigation for each of the soils indicated in question 22? (for intermittent field irrigation only).**

surface soil	sand		loam		silt		silty clay		clay		heavy clay		
texture sub str.	light	heavy	light	heavy	light	heavy	light	heavy	light	heavy	light	heavy	
22. ground-water table not measurable													
depth below surface				4.60	4.00	4.00	3.00	2.00	2.00	1.50	1.50		m/~~ft~~
23. annual fluctuation			0.60	0.60	→								m/~~ft~~
24. ground water: non-saline													
slightly saline			X	X	X	X	X	X	X	X	X		
moderately saline													
strongly saline													
25. depth per irrigation			200	200	200	200	200	200	200	200	200		mm/~~inches~~

26. What is the interval between two water applications for each of the indicated soils during the different months of the growing season(s)? (for intermittent field irrigation only).

26.

surface soil	texture substratum	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
														days
	loam	20	18	17	17	15	22	20	27	29	26	24	19	days
	silt loam	25	23	20	20	20	29	33	31	30	28	26	27	days
	clay loam	25	24	22	21	21	30	33	32	31	29	29	29	days
	clay	29	29	28	26	25	31	37	38	34	33	30	28	days
	heavy clay	30	30	29	26	25	32	38	40	38	37	29	29	days

27. Is the irrigation water supplied free of charge to the farm, or, if any water charges are paid by the farmer, are these based on a fixed annual amount, or on a unit rate for volume, for cropped area, or for total area of the farm, or on a combination of one of these proportional charges and a fixed amount, or on any other criteria?

27. water charges

	free of charge	fixed amount	proportional charge based on :			combination fixed amount and proportional charge on			other criteria
			volume	cropped area	total area	volume	cropped area	total area	
farm type A				X					
farm type B				X					
farm type C									

28. What are the average annual water charges for the typical farm(s)?

1) $ 20.00 per hectare and per each irrigation

28. annual charge

				X 1)					
farm type A				$ 151.20					
farm type B				$ 428.40					
farm type C									

29. Do the farmers irrigate alone, with the help of the members of their family, with the help of hired labour, with the help of unpaid other farmers, or is the irrigation carried out by paid special labour?

29. Irrigation by

	farmer alone	farmer with family	farmer with hired labour	farmer with other farmers	special labour
farm type A		X	X		
farm type B		X	X		
farm type C					

30. If the farmer receives assistance for irrigation from other farmers, are these mainly neighbours, or kinsmen, or related by the same place of origin or friends?

30, assistance by other farmers

neighbours	kinsmen	related by same place of origin	friends
	X		

31. **If neighbours assist each other with their irrigation, is such assistance incidental, or do they belong to a group of farmers?**

31. **assisting neighbours**

incidental assistance	neighbours belonging to a group

000

C. AGRICULTURE (*continued*)

32. Do groups of neighbouring farmers irrigate simultaneously?

32.

non-simultaneous irr.	simultaneous irr.
X	

33. If groups of neighbouring farmers exist, either for assistance during irrigation or because the farmers of such groups irrigate simultaneously, how many farmers belong to one group. Are these groups only operating for irrigation purposes, or do they have other collective activities?

33. number of farmers in one irrigation group

≮ 5	5—15	15—50	> 50

○○○

other purposes of groups

irrigation only	other agr. purp.	other non-agr. purp.

34. If groups of farmers, next to irrigation, also co-operate for other agricultural purposes, what are usually these collective agricultural activities?

34. other agr. group activities by irrigation groups

35. If in irrigation no groups of farmers co-operate, do any groups of farmers exist for other agricultural activities and if so, what are usually these activities?

35. by other groups

soil preparation	sowing	weeding	harvesting	processing

○○○

36. If farmers co-operate in groups for irrigation, or for other agricultural purposes, do these groups have a recognized position in the contacts with irrigation officials, the community organisation, the extension service, or the land-owner?

36. groups recognised by

irrigation officials	community organisation	extension service	landowner	no recognition

○○○

37. irrigation groups exist, and if the irrigation water is delivered by way of group inlets, is then one irrigation group served by one or by several group inlets, and in case of one group inlet, are all farmers served by one group inlet one or more irrigation groups?

37. one irrigation group served by

one inlet	several inlets

○○○

one group inlet serves

one irrig. group	several irr. groups

38. If the irrigation water is delivered by way of a group inlet, who controls the distribution to the farms (or plots) downstream of the group inlet, and is this control carried out according to a fixed rotation, a periodical schedule or (an) incidental decision(s)?

38.

control of distribution	by central irrigation organisation	by a special distribution organisation	by a specially assigned official	by group of farmers	by each individual farmer	by other organisations or person
distr. in fixed rotation						
distr. acc. to schedule			X			
distr. acc. to incidental decision						

C. AGRICULTURE *(continued)*

SERIAL No...... SHEET 13

39. Do any co-operatives exist in the area, and if so, what is the purpose of each of the co-operatives?

39. purpose of co-ops

	purchase co-op	production co-op	marketing co-op	irrigation co-op	consumers co-op	co-op for other purpose	No co-operatives
co-op No. 1							
co-op No. 2							
co-op No. 3							
co-op No. 4							

OOO

40. Have the above indicated co-operatives been established by *the initiative of the farmers, of the government*, of the irrigation or project authority or by other initiatives?

40. co-ops by initiative

	farmers	governments	irrigation or project authority	by other initiative
co-op No. 1				
co-op No. 2				
co-op No. 3				
co-op No. 4				

OOO

41. In which way are the executive positions staffed in the various co-operatives?

41. staff of co-operatives

	unpaid members	paid members	members and paid officials	paid officials
co-op No. 1				
co-op No. 2				
co-op No. 3				
co-op No. 4				

OOO

42. Does an agricultural extension service operate in the area and if so, in what degree have the officials of this service contact with groups of farmers or with individual farmers?

42. extension service

no extension service	*regular contact*	*incidental contact*	*no contact*
	X		

43. If the officials of the extension service have regular or incidental contacts with the farmers, do they give advice, or demonstrations, or instructions on the cultural practices or and irrigation, and if so, *do these include water distribution, water requirements*, irrigation methods and equipment, soil preparation, land levelling, field ditches, or field drainage?

43. advice etc.

no cult. pract. or irrigation	advice etc. on cultural practices and irrigation					
	water distribution	water requirements	methods-equipment	soil preparation	land levelling field ditches	field drainage
	X1	X2		X3		X4

44. Further information :

x) Overall supply is sufficient for about 85 % of area.
Several canal sections have a too low capacity.

SERIAL NO. 4 SHEET 14

D. EVALUATION

1. Please, will you indicate your opinion according to the different categories of performance as to the following questions:
   (a) how is the overall supply of the area with irrigation water during the growing season(s) under average hydrological and meteorological conditions?
   (b) how is the efficiency of the conveyance and distribution of the supply up to the group inlets, or farm inlets in case no group inlets exist?
   (c) how is the supply in general to the farm inlets (or inlets of farm plots), particularly in respect of the size, the timing and the duration of the available flow?
   (d) how is the efficiency of the conveyance and the distribution of the supply from the group inlets to the farm inlets (or inlets of farm plots)? (only in case the laterals or sub-laterals deliver the flow to group inlets.)
   (e) how is the efficiency of the conveyance and the distribution to the fields downstream of the farm inlet?
   (f) how is the field irrigation efficiency?

1. Opinion x)	adequate	sufficient	insufficient	poor
(a) overall supply			X	
(b) efficiency to group or to farm inlets			X	
(c) supply to farm inlets		X		
(d) efficiency from group inlet to farm inlet				X
(e) efficiency from farm inlet to field				X
(f) field irrigation efficiency				X

2. If farmers co-operate in the distribution of water, either in groups or incidentally, do conflicts and discord occur among the farmers with respect to :
   (a) the flow made available to them,
   (b) the time and duration of the delivery of this flow,
   (c) the work to be carried out by the farmers for the water distribution
   (d) the maintenance of ditches and structures?

2. Conflicts among farmers	never	rarely	occasionally	frequently
(a) available flow	X			
(b) time and duration	X			
(c) work for distribution	X			
(d) maintenance	X			

3. Do the groups of farmers or the individual farmers have conflicts with, or complaints about, the organisation(s) in charge of the diversion. conveyance and distribution of the supply and of the delivery to the group inlets or farm inlets, with respect to :
   (a) the flow made available to the group inlets or farm inlets.
   (b) the time and the duration of the delivery of this flow.
   (c) the work to be carried out by the farmers for the water distribution.
   (d) the maintenance of ditches and structures?

3. Conflicts with organisation				
(a) available flow			X	
(b) time and duration		X		
(c) work for distribution	X			
(d) maintenance			X	

D.EVALUATION. *(continued)* SERIAL NO.......SHEET 15

4. Does an individual farmer have direct or indirect communication with the organisation(s) in charge of the diversion and conveyance of the irrigation supply and of the delivery thereof to the group inlets or farm inlets, and if so, how does this communication work out in case the farmer has a demand or a special request with respect to the water delivery to his farm?

4. communication

direct or indirect communication				no communication
adequate	sufficient	insufficient	poor	
	X			

5. Are any major changes regarding the facilities, the methods, or the organisation of the water distribution under execution, proposed, under preparation, contemplated or considered desirable, and if so, of what nature are these changes?

5. changes

	No major change	major changes				
		under execution	proposed	under preparation	contemplated	considered desirable
technical works for storage	X					
diversion works			X1			X2
conveyance works			X1			X2
technical works for distribution		X1	X2			X3
farm ditches				X1		X2
land levelling						X
land drainage		X3	X2	X1		X4
distribution methods		X1				X2
methods of field irrigation		X3	X1	X2	X4	X5
organisation of conveyance		X				
organisation of distribution		X				
other changes						

6. Can any further information be given regarding the presently existing problems of, for instance water economy, irrigation efficiency, unbalanced demand and supply, wastages, and the possibilities of solving these problems?

6. Further information

Appendix II
Forms used to calculate water utilization efficiencies

COUNTRY:	CODE	9	3	4

AGRICULTURAL AREA	97000	→ 100	%
IRRIGATED AREA	38512	→ 40	%

IRRIGATED AREA		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OKT	NOV	DEC
			20.3	23.1	25.6	23.5	24.8	27.9	28.4	25.7	18.2	12.7	12.8	18.5
	%	average 56	53	60	66	61	64	72	74	67	47	33	33	48
CROP 1	%	13	13	13	13	13	13	13	13	13	13	13	13	13
2	%	32			32	32	32	32	32	32				
3	%	16	16	16	16	16								16
4	%	4			4	4	4	4	4	4				
5	%	16	16									16	16	16
TOTAL AREA	%	average 43	45	29	65	65	49	49	49	49	13	29	29	45

FALLOW X %

IRRIGATED CROPS	
1	alfalfa
2	mais
3	wheat and barley
4	tomato
5	forrage (oats)
6	
7	

		CROP 1	CROP 2	CROP 3	CROP 4	CROP 5
IRRIGATION METHOD	basin	X		X		
	furrow		X		X	X
	border strip	X				
	sprinkler					

934

		CROP 1–5	APPLICATION DEPTH mm
SOIL TYPE	light	} various soil types	}
	medium		200
	heavy		

INTERVAL IN DAYS	soil type	J	F	M	A	M	J	J	A	S	O	N	D	average month		sum year		number of turns
	L	20	18	17	17	15	22	20	27	29	26	24	19	21		254		
														1.4	x	12	=	17
	M	25	24	22	21	21	30	33	32	31	29	29	29	27		326		
														1.1	x	12	=	13
	H	30	30	29	26	25	32	38	40	38	37	29	29	32		383		
														.94	x	12	=	11
average soil																		13.6

NUMBER OF TURNS		J	F	M	A	M	J	J	A	S	O	N	D		number of turns
farm	A	1	1	1	2	2	1	1	1	1	1	1	1		14
	B	1	1	–	2	2	–	1	1	1	1	1	1		12
	C														
average farm															13

		FARM A	FARM B	FARM C	average
farm flow	l/s	100	100		
delivery time	hours	7	19		
farm size	ha	1.2	3.4		
delivery	mm	210	201		205

AVERAGE APPLICATION DEPTH PER TURN: 203

AVERAGE NUMBER OF TURNS PER YEAR: 13.5

V_d = 43 % of 203 x 13.5

V_d = 1180 mm

9	3	4

CONSUMPTIVE USE (W)		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MONTHLY AVERAGE	YEAR SUM	% TOTAL AREA	CONTRIBUTION PER CROP
CROP	1	25	34	66	93	124	142	158	164	151	139	114	98		1308	13	170
	2			43	91	148	168	154	108						712	32	228
	3	102	132	150	87								46		517	16	83
	4			37	79	29	146	138	101						632	4	25
	5	100									130	70	100		400	16	64
TOTAL AREA																81	570

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MONTHLY AVERAGE	YEAR SUM	% TOTAL AREA	CONTRIBUTION PER CROP
PRECIPITATION	11	11	4	26	21	58	92	156	25	28	8	26		466		
EFFECTIVE PRECIPITATION (P_e)	2	2	0	11	7	23	40	50	10	11	2	10		163	x .43	70
$V_m = W - P_e$																500

FIELD APPLICATION		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MONTHLY AVERAGE	YEAR SUM	% TOTAL AREA	CONTRIBUTION PER CROP
CROP	1	45	60	115	169	218	250	277	287	265	243	200	172		2291	13	298
															.57		
	2			75	160	260	295	270	189						1250	32	400
															.57		
	3	179	232	263	153								82		908	16	145
															.57		
	4			65	138	226	256	243	177						1105	4	44
															.57		
	5	75									228	123	175		702	16	112
															.57		
TOTAL AREA V_f																	999

9	3	4

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OKT	NOV	DEC	AREA PERCENTAGE	YEAR SUM
FARM SUPPLY A	94	94	120	118	118	98	104	110	74	84	86	99	—	
B	94	94	.120	118	118	98	104	110	74	84	86	99		
C														
average mm/month	94	94	120	118	118	98	104	110	74	84	86	99	100	V_d 1199
PROJECT SUPPLY m^3/s	27.3	34.3	34.4	32.6	33.3	38.8	38.2	34.5	25.3	17.1	17.8	24.9		358.5
IRRIGATED AREA ha x 10^3	20.3	23.1	25.6	23.5	24.8	27.9	28.4	25.7	18.2	12.7	12.8	18.5		
SUPPLY OVER IRRIGATED AREA mm/month	347	383	347	360	347	360	350	347	360	350	360	350		V_c = 2412

EFFICIENCIES

e_p	e_u	e_s	e_a	e_d	e_c
.21	.42	.41	.50	.83	.50

Appendix III
Tables of basic data as supplied by the questionnaire

Table A Answers to Questions A13 and A14 (see Section 6.1.1)

Code	e_c	e_s	Irrigable area (ha) A13	Irrigated area (ha) A14
		GROUP I		
912	.87	.78	5400	3500
915	.51	.33	1900	1900
321	.66	.46	48500	1642
512	.70	.58	236	189
513	.67	.34	212050	147150
514	.78	.47	–	181
515	.67	.34	55000	30000
518	.50	.29	16	12.5
931	.48	.31	232550	167800
932	.91	.77	14057	12540
933	.86	.52	–	51000
934	.50	.41	97000	38512
421	.71	.57	360	360
422	.56	–	359	359
		GROUP II		
611	.83	.75	1250	1173
612	.94	.85	720	712
613	.92	.80	433	402
614	.97	.92	1414	1285
615	.97	.87	361	353
622	.90	.72	9394	8982
631	.89	.76	19700	18800
632	.80	.54	10120	10000
633	.88	.86	26040	24800
642	.92	.87	4000	3600
652	.56	.34	82967	25600
653	.98	.93	38	38
		GROUP III		
311	.81	.78	12300	3900
313	.88	.74	1100	1100
211	.94	.79	7100	5940
212	.64	.63	930	930
214	–	.40	2600	2100
215	.82	.69	14000	14000
221	.96	.48	1650	1350
222	.59	.31	250	144
223	.85	.51	2200	1800
232	.56	.36	28540	22335

Table A (cont.)

233	.67	*.47*	20800	19760
241	*.77*	.46	2100	1600
251	*.89*	.58	1700	650
352	.42	*.37*	24782	10317
821	*.83*	.66	7135	5250
822	*.88*	.70	4945	4180
824	*.54*	.52	19110	16000
826	*.63*	.50	96400	60000
		GROUP IV		
112	*.75*	.60	19000	5000
121	*.80*	.64	2918	2920
122	*.44*	.35	80000	45000

Table B Size of rotational unit in ha (Questions A13, B7, B13, B15 and B16) (see Section 6.1.2)

		Size of rotational unit in ha								
Code	e_c	< 5	5-10	10-50	50-100	100-200	200-500	500-1000	1000-5000	> 5000
GROUP I										
912	*.87*					x				
915	*.51*									6500
321	*.66*								1640	
514	*.78*							500		
515	.67								x	
518	.50		x							
932	*.91*			x						
933	.86							x		
934	.50									38500
421	.71			x						
422	.56			15						
652	.56								x	
512	.70						236			
GROUP III										
311	.81							x		
313	.88					x				
211	.94					200				
221	.96				x	x				
222	.59		x							
223	*.85*				x					
232	.56									24000
233	.67				x					
241	*.77*			x						
251	*.89*			40						
821	*.83*				100					
822	*.88*				80					
824	*.54*									16000
826	*.63*								x	

Table C Answers to Questions B4 and B5 (see Section 6.1.1)

Code	e_c	Flow regulating structures: None	Temp. controls	Fixed structures	Movable gates (manual)	Autom. devices	Others
GROUP I							
912	.87				x		
915	.51			x	x		
321	.66				x		
512	.70				x		
513	.67				x		
514	.78				x		
515	.67				x		
518	.50		x				
931	.48			x	x		x
932	.91			x			
933	.86			x	x		
934	.50				x		
421	.71			x			
422	.56			x			
652	.56			x	x		
Average e_c		–	.50	.65	.69	–	.48
GROUP III							
311	.81				x		
313	.88		x	x			
211	.94			x			x
212	.64					x	
215	.82					x	
221	.96				x		
222	.59			x			
223	.85		x	x	x	x	
232	.56		x	x	x	x	
233	.67				x		
241	.77			x			
251	.89		x	x	x	x	x
352	.42				x		
821	.83				x	x	
822	.88				x		
824	.54				x		
826	.63				x	x	
Average e_c		–	.77	.74	.72	.72	.92

Table C (cont.)

Code	e_c	Lining of canals: All canals lined	Main, lateral, and sublaterals lined	Main and laterals lined	Main canal lined	All canals earthen
GROUP I						
912	*.87*					x
915	*.51*			x		
321	*.66*					x
512	.70					x
513	.67					x
514	*.78*					x
515	.67					x
518	.50					x
931	*.48*				x	
932	*.91*	x				
933	.86			x		
934	.50			x		
421	.71	x				
422	.56	x				
652	.56		x			
Average e_c		.69	.56	.62	.48	.67
GROUP III						
311	.81			x		
313	.88					x
211	.94			x		
212	.64	x				
215	.82	x				
221	.96		x			
222	.59	x				
223	*.85*	x				
232	.56			x		
233	.67					x
241	*.77*	x				
251	*.89*	x				
352	.42		x			
821	*.83*			x		
822	*.88*			x		
824	*.54*					x
826	*.63*	x				
Average e_c		.72	.69	.79	–	.73

Table D Answers to Questions C4, C5, C15, C16, and C25 (see Sections 6.3.2, 6.3.3 and 6.3.4)

Code	Farm size (ha)	Size of farm plot (ha)	Flow at farm inlet (l.s.)	Flow duration farm (hours)	Average depth per application (mm)
912	100	–	350	180	25
	50	–	200	90	
	30	–	–	–	
915	8	–	20	18	–
	35	–	100	18	
	>50	–	>150	18	
321	–	1.4	60[1]	1[1]	80
512	10	0.1	–	–	
	4	to	42[2]	8[2]	75
	1	5.0	–	–	
513	1 to 4	0.1	34[1]	.75[1]	100
514	4	–	12	72	80
	2	–	7	60	75
	0.4	–	7	12	75
518	6	–	28	12	
	4	–	21	8	60 to 120
	2	–	8.5	3	
931	10	–	90[3]	36[3]	120
	19	–	125[3]	52[3]	
932	8	–	30	144	190
	30	–	45	168	90
933	2	2	100	12	220
	10	–	150	42	
	50	–	250	120	
934	1.2	1.2	100	7	200
	3.4	3.4	100	19	
421	about 2.0	0.5	20	24	80
422	1.0	0.5	15	12	70
652		0.3	35[1]	2.5[1]	100
GROUP II					
311	1.6	0.4	28	14	100
	4	0.6	28	40	
	8	0.8	28	70	
312	0.2	0.2	6	5	70
	0.6	0.2	8.5	5	
	2	–	11.5	35	
313	2.3	0.87	10	35	63
221	2.4	2.4	40	24	110
	1.2	1.2	40	12	
	0.6	0.6	40	6	
222	2.3	2.3	57	9	80
223	0.6	0.1	200	.10[4]	72
	1.0	0.3	200	.25[4]	
241	0.74	0.22	10	[5]	75
351	3.4	about 0.8	40 to	–	
	10.9	about 2.5	60		
352	2.7	0.4	10 to 40	4 to 8	–
	8.5	1.4	40 to 60	8 to 16	
	21.3	3.6	> 60	24 to 36	
821	130	–	141	288	110
	65	–	113	180	

Table D (cont.)

	32	4	85	120	
822	55		70	120	–
	18	about 8	70	96	–
824	65	–	85	168	125
826	65	16	226	142	–
	130	16	453	142	
	324	16	906	177	
827	65	32.5	370	18	183

1 values per farm plot
2 flow 5 h/ha farm plot
3 average values
4 values per farm plot (basins)
5 20 h/ha

Table E Answers to Question C4 (see Section 6.2.1)

GROUP II		
Code	E_d	Average farm size (ha)
611	*.90*	0.05
612	*.90*	0.03
613	.87	0.1
614	*.95*	0.05
615	*.90*	0.1
622	*.80*	1.5
631	*.85*	1.0
632	*.68*	0.8
633	*.97*	1.6
641	–	2.8
642	*.95*	2.3
653	*.95*	0.85
661	–	< 5

Table F Answers to Question C25

GROUP IV		Depth per application in mm per soil type						Average depth per application mm
Code	e_a	Sand	Loam	Silt	Silty clay	Clay	Heavy clay	
111	.75	50	50					50
112	.49				30	80		55
121	.46	200						200
122	.57	30-60						45
124	.81	30	30	30	40	40	40	35
131	.88	25						25
212	.71			50				50
214	.70	20	25	30	30			25
215	.66	u						45
219	.71		30		30			30
221	.65			100	120			110
251	.51		80					80
811	.45	u						–

u = unknown soil type

Table G Answers to Questions C1, C5, C14, C18 and calculation of average efficiencies shown in Figure 12, Section 6.3.1
a) Irrigated areas with flow irrigation (furrow and border strip)

		Percentage distribution of area acc. to soil type					
Code	e_a	Sand	Loam	Silt	Silty clay	Clay	Heavy clay
211	.39	20	30	30	20^{00}		
222	.65		100^{70}				
223	.59	50	50				
232	.56	100					
233	.61		100				
241	.72	20	30		30	20^{10}	
251	.51		100^{80}				
311	.52		10^{00}	40^{30}	50^{40}		
313	.52			30	40^{20}	20^{00}	10^{00}
421	.47					100	
711	.67	40	40			20	
821	.40		30	40^{30}	30^{00}		
822	.58	20	20	20	20^{00}	20^{00}	
824	.55				100		
826	.59		100				
827	.71	20	20	20^{00}	20^{00}	20^{00}	
652	.64		30	40^{20}	30^{00}		
661	.38					100^{40}	
512	.70					80^{30}	20^{00}
513	.40		50			50^{30}	
518	.51		30			40	30
912	.42					100^{50}	
915	.38	30	40			30	
931	.87		30	20^{10}	20^{00}	30^{00}	
932	.66		100^{80}				
933	.45					80^{40}	20^{00}
Σ area Percentages		300	830	170	190	380	30

a) cont.

Percentage distribution of irrigation method				Relevant soil type percentage multiplied by e_a					
Basin	Furrow	Border	Sprinkler	Sand	Loam	Silt	Silty clay	Clay	Heavy clay
20	80			7.8	11.7	11.7			
30	40	30			45.5				
	90	10		29.5	29.5				
	50	50		56.0					
		100			61.0				
10	90			14.4	21.6		21.6	7.2	
	80		20		40.8				
10	70		20			15.6	20.8		
50	50					15.6	10.4		
		100						47.0	
	50	50		26.8	26.8			13.4	
40		60			12.0	12.0			

Table G (cont.)

40	40	20	11.6	11.6	11.6			
	90	10				55.0		
	60	40		59.0				
60	40		14.2	14.2				
50	40	10		19.2	12.8			
60		40					15.2	
70	30						21.0	
20	40	40		20.0			12.0	
	90	10		15.3			20.4	15.3
50		50					21.0	
	60	40	11.4	15.2			11.4	
60	20	20		26.1	8.7			
20	80							
60	40						18.0	
		$\Sigma e_a \times \%$	171.7	482.3	88.0	107.8	186.6	15.3
$\frac{\Sigma e_a \times \%}{\Sigma \text{area } \%}$ = average e_a			.57	.58	.52	.57	.49	.51

b) Irrigated areas with intermittent basin irrigation

		Percentage distribution of area acc. to soil type					
Code	e_a	Sand	Loam	Silt	Silty clay	Clay	Heavy clay
211	.39	20^{00}	30^{00}	30^{00}	20		
221	.65			50^{10}	50		
222	.65		100^{30}				
241	.72	20^{00}	30^{00}		30^{00}	20^{10}	
311	.52		10^{00}	40^{00}	50^{40}		
312	.62	50	50				
313	.52			30^{00}	40^{20}	20	10
821	.40		30^{00}	40^{10}	30		
822	.58	20^{00}	20^{00}	20^{00}	20	20	
827	.71	20^{00}	20^{00}	20	20	20	
512	.70					80^{50}	20
513	.40		50^{00}			50^{20}	
514	.53		100				
515	.47					100	
912	.42					100^{50}	
931	.87		30^{00}	20^{10}	20	30	
932	.66		100^{20}				
933	.45					80^{40}	20
Σ area percentages		50	200	50	220	360	50

Table G (cont.)
b) cont.

Percentage distribution of irrigation method				Relevant soil type percentage multiplied by e_a					
Basin	Furrow	Border	Sprinkler	Sand	Loam	Silt	Silty clay	Clay	Heavy clay
20	80						7.8		
60	20		20			6.5	32.5		
30	40	30			19.5				
10	90							7.2	
10		70	20				20.8		
100				31.0	31.0				
50	50						10.4	10.4	5.2
40	60					4.0	12.0		
40	40	20					11.6	11.6	
60	40					14.2	14.2	14.2	
70	30							35.0	14.0
20	40	40						8.0	
100					53.0				
100								47.0	
50		50						21.0	
60	20	20				8.7	17.4	26.1	
20	80				13.2			26.4	
60	40								9.0
		$\Sigma e_a \times \%$		31.0	116.7	33.4	126.7	206.9	28.2
$\frac{\Sigma e_a \times \%}{\Sigma area \%}$ = average e_a				.62	.58	.66	.58	.57	.56

c) Irrigated areas with sprinkler irrigation

		Percentage distribution of area acc. to soil type					
Code	e_a	Sand	Loam	Silt	Silty clay	Clay	Heavy clay
111	.75	50	50				
112	.49				30	40	30
122	.57	100					
124	.81	20	10	20	20	10	20
131	.88	100					
212	.71			100			
214	.70			100			
215	.66	10	40	10	40		
219	.71		50		50		
221	.65			50^{20}	50^{00}		
251	.51		100^{20}				
811	.45	20	20	20	20	20	
Σ area percentages		300	190	270	160	70	50

Table G (cont.)
c) cont.

Percentage distribution of irrigation method				Relevant soil type percentage multiplied by e_a					
Basin	Furrow	Border	Sprinkler	Sand	Loam	Silt	Silty clay	Clay	Heavy clay
			100	37.5	37.5				
			100				14.7	19.6	14.7
			100	57.0					
			100	16.2	8.1	16.2	16.2	8.1	16.2
			100	88.0					
			100			71.0			
			100			70.0			
			100	6.6	26.4	6.6	26.4		
			100		35.5		35.5		
60	20		20			13.0			
	80		20		10.2				
			100	9.0	9.0	9.0	9.0	9.0	
		$\Sigma\, e_a \times \%$		214.3	126.7	185.8	101.8	36.7	30.9
$\frac{\Sigma e_a \times \%}{\Sigma \text{area } \%}$ = average e_a				.71	.67	.69	.64	.52	.62

d) Areas with basin irrigation with continuous supply (rice)

		Percentage distribution of area acc. to soil type					
Code	e_a	Sand	Loam	Silt	Silty clay	Clay	Heavy clay
611	.45						
612	.26						
613	.14		soil data not available				
614	.27						
615	.22						
622	*.35*		100				
631	*.40*	30	40	30			
632	*.25*		100				
633	.39					100	
641	.52				100		
642	.45				100		
653	.36					100	
661	.38					100[60]	
913	.11		100				
914	.13	40	20	20	20		
Σ area percentages		70	360	50	250	260	0

Table G (cont.)
d) cont.

Percentage distribution of irrigation method				Relevant soil type percentage multiplied by e_a					
Basin	Furrow	Border	Sprinkler	Sand	Loam	Silt	Silty clay	Clay	Heavy clay
100									
100									
100									
100									
100									
100					35.0				
100				12.0	16.0	12.0			
100					25.0				
100								39.0	
100							52.0		
100							45.0		
100								36.0	
60		40						22.8	
100					11.0				
100				5.2	2.6	2.6	2.6		
		$\Sigma e_a \times \%$		17.2	89.6	14.6	118.8	97.8	–
$\frac{\Sigma e_a \times \%}{\Sigma area \ \%}$ = average e_a				.24	.25	.29	.45	.38	–

NOTE:
In calculating the average e_a-values, which are presented graphically in Figure 12, the procedure was as follows: The sum of the percentages showing the soil type distribution was reduced to the same value as that for the relevant irrigation method. The corrected percentages appear as small figures in the tables. In making these reductions, it was assumed that basins occurred mainly on heavy (relatively flat) soils, and that flow and sprinkler irrigation occurred on lighter soils, sprinkler being used mostly on light (sloping land) soils.

Table H Answers to Questions B18, C27 and C28 (see Section 6.4.2)

Code	e_u	Score for water charges (B18). See key at bottom table				Method of charging (C27) See key	Approximate charge per ha in local currency	Exchange rate to US.$ and (year)
		O	+ M	+ Cap	= Total			
121	*.37*	1 +	1 +	0 =	2	b	120	3.24
122	*.37*	3	3	10	16	b	–	(1972)
123	*.18*	–	–	–	1.5	b	80	
124	.63	3	3	0	6	f	.15 to .25/m^3	
131	.70	3	3	10	16	e	–	3.20
132	*.41**	2	2	8	12	e	100	(1972)
211	.33	3	3	8	14	c	260	5.09
212	.69	3	3	4	10	f	370	(1972)
213	–	3	3	0	6	e	100	
214	.67	3	3	4	10	f	250	
215	.56	3	3	4	10	f	250	
216	.62	3	3	10	16	f	80	
217	–	1	3	0	4	f	40	
218	–	3	3	10	16	c	425	

Table H (cont.)

Code	e_u	Score for water charges (B18). See key at bottom table				Method of charging (C27) See key	Approximate charge per ha in local currency	Exchange rate to US.$ and (year)
		O	+ M	+ Cap	= Total			
219	.71	3	3	10	16	f	250	
221	.37	2	2	0	4	d and e	210	30
222	.34	3	1	0	4	g	150	(1972)
223	.36	3	3	0	6	g	40	
224	.50*	3	3	4	10	g	400	
231	–	3	3	10	16	g	20 000	629
232	.36	3	3	0	6	f	11 000	(1970)
233	.43	3	2	8	13	h	7 500	
241	.43	3	3	0	6	d	400	27
251	.33	3	3	8	14	f	1 000	67
311	.51	3	2	4	9	c	8/m^3	380
312	.49*	3	2	4	9	c	12/m^3	(1972)
313	.44	2	2	8	12	e	100 000/ha	
321	.46	3	3	0	6	g	2.5	0.44 (1969)
332	.51*	3	2	4	9	a and d	–	
351	.56	2	2	10	14	d	60	
352	.61	2	2	10	14	d	75	(1971)
421	.45	3	2	0	5	g	56	0.67
512	.57	3	3	4	10	d	81	7.5
513	.20	3	3	4	10	d	25	(1972)
514	.32	3	2	0	5	d	25	
515	.24	3	1	0	4	h	–	
518	.30	3	3	0	6	g	40	
611	.41	1	2	0	3	e	8 000	308
612	.23	3	0	0	3	c	560	(1972)
613	.12	1	2	0	3	e	6 000	
614	.26	2	0	0	2	e	6 000	
615	.20	0	0	0	0	e	–	
621	–	3	3	10	16	e	25 415	372
622	.28	3	3	10	16	d	22 170	(1972)
631	.34	2	0	0	2	c	24	2.85
632	.17	2	0	0	2	e	7.5	(1972)
634	–	1	1	0	2	e	15	
642	.43	3	3	0	6	g	48	3.98
652	.40	3	3	10	16	e	2 000	40
653	.34	0	0	0	0	g	1 630	(1972)
711	.53*	3	2	0	5	c + i	25 plus 100 for extra watering	0.83 (1972)
821	.32*	3	3	4	10	h	14	1
822	.46*	3	3	4	10	e	10	(1971)
824	.53	3	3	10	16	f and h	12	
826	.47*	1	1	4	6	f and h	–	
827	.56*	3	3	0	6	f and h	25	
912	.38	3	1	0	4	f and h	123 plus 0.006 m^3	23
915	.25	3	2	0	5	f and h	–	(1972)
931	.57	3	3	0	6	c	100	12.5
932	.56	3	1	0	4	c	85	(1971)
933	.27	1	0	0	1	f	80 plus 0.015/m^3	
934	.42	2	2	0	4	g	125 plus 20/turn	

* the e_a-value from Table 2 has been multiplied with an (average) e_d = 0.80 to obtain the shown e_u-value

Key to score for Question B18: Water charges

	Coverage by water charges			
	None	0 – 50%	50 – 100%	Complete
(a) operation costs	0	1	2	3
(b) in addition maintenance costs	0	1	2	3
(c) in addition capital costs	0	4	8	10

Key to Table H for Question C27: Water charges

	Letter in Table H
Free of charge	a
Fixed amount	b
Proportional charge based on:	
Volume	c
Cropped area	d
Total area	e
Combination of fixed amount & proportional charge on:	
Volume	f
Cropped area	g
Total area	h
Other criteria	i

Table I Answers to Questions B7, B13, C14 and C15 (see Section 6.4.3)

Code	e_u	e_c	Distribution method			
			A	B	C	D
Group I						
912	*.38*	*.87*	x			
915	*.25*	*.51*		x		
321	*.46*	*.66*		x		
512	.57	.70		x		
513	.20	.67		x		
514	*.32*	*.78*		x		
515	.24	.67		x		
518	.30	.50		x		
931	.57	*.48*			x	
932	*.56*	*.91*		x		
933	.27	.86		x		
934	.42	.50			x	
421	.45	.71		x		
422	.86	.56		x		
652	.40	.56		x		

Table I (cont.)

Group II						
611	*.41*	.83	x			
612	*.23*	.94	x			
613	.12	.92	x			
614	*.26*	.97	x			
615	*.20*	.97	x			
622	.28	.90	x			
631	*.34*	.89	x			
632	.17	*.80*	x			
633	*.39*	.86	x			
642	*.43*	*.92*	x			
653	*.34*	.98	x			
Group III						
311	.51	.81			x	
313	.44	.88		x		
211	.33	.94		x		
212	.69	.64				x
214	.67	–				x
215	.56	.82				x
221	.37	.96		x		
222	.34	.59		x		
232	.36	.56		x		
233	.43	.67		x		
241	*.43*	*.77*		x		
251	*.33*	*.89*		x		
351	.56	*.26*			x	
352	.61	.42			x	
824	*.53*	*.54*			x	
216	.62	–				x
218	.94	–				x
219	.71	–				x
Average		e_u	.27	.41	.53	.70
Average		e_c	.91	.70	.53	.73

Table J Answers to Question D1 (see Section 6.5.2)

Code	e_s	Direct or indirect communication between irrigation service and farmers			
		Adequate	Sufficient	Insufficient	Poor
GROUP I					
915	.33	x			
321	*.46*[1]	x			
512	*.58*	x			
513	.34	x			
514	.47	x			
515	*.34*[1]		x		
518	.29		x		

Table J (cont.)

931	.31		x		
932	.77	x			
933	.52	x			
934	.41		x		
421	.57		x		
652	.34		x		
	average e_s	.48	.41	–	–
GROUP III					
311	.78	x			
313	.74		x		
211	.79	x			
212	.63	x			
214	.40		x		
215	.69	x			
221	.48		x		
222	.31	x			
223	.51	x			
232	.36		x		
233	*.47*[1]	x			
241	.46		x		
251	.58	x			
351	*.22*[1]				x
352	*.37*[1]				x
821	.66	x			
822	.70	x			
824	.52		x		
826	.50	x			
GROUP III		.61	.49	–	.30
GROUP I + III		.57	.45	–	.30

[1] values have 50% weight

APPENDIX IV
THE INFLUENCE OF UNIFORMITY AND LEACHING ON THE FIELD APPLICATION EFFICIENCY [1]

M.R. Till
M.G. Bos

1 Introduction

The purpose of this discussion paper is to:
- Indicate the importance of the uniformity of application of irrigation water in interpreting the field application efficiency term (e_a, Bos 1980);
- Discuss the usefulness of a uniformity factor which takes into account non-uniformity application of water, and how such a factor could be derived;
- Show how the actual field application efficiency would be limited by the non-uniform application of water;
- Discuss how other 'beneficial uses' of water may limit the field application efficiency (e_a).

The field application efficiency was originally defined by the ICID Working Group on Irrigation Efficiency as the ratio between the mean depth of irrigation water supplied. To the field V_f and the depth of irrigation water needed, and made available, for evapotranspiration by the crop so as to avoid undesirable water stress in the plants throughout the growing cycle V_m (Bos 1980).

The field application efficiency can be expressed as

$$e_a = 100\, V_m/V_f \text{ per cent} \qquad (1)$$

Under given climatological conditions the value of V_m for the irrigated crop can be estimated. The value of V_m is, however, most often determined by the answer of the irrigator to the classical questions: 'When do I irrigate?' and 'How much?'. The field application efficiency therefore is an index of how well the management of the field irrigation system supplied water for crop growth. In design, it is the efficiency that is to be expected with a given system and operator.

In this context it is stressed that the target value of e_a is always below 100 per cent. This target value depends, among other things, on the quantity of water needed to limit the undesirable effects of:
- Insufficient irrigation water in part of the field due to non-uniform application of water;
- Inadequate leaching to maintain an acceptable salt balance in the rootzone;
- A practical or economical (labour) limitation on the area of fields under surface irrigation.

In this paper special attention will be given to the first two factors.

[1]) ICID Bulletin, January 1985, Vol. 34, No. 1

2 Uniformity of water application

The ability to apply water uniformly to a field is an important criterion in deciding which irrigation method to employ. Restoring soil moisture and accomplishing leaching uniformly on all parts of a field are extremely difficult because:

- Soils are seldom homogeneous across the entire field;
- Land grading is seldom sufficiently precise for the method of irrigation employed;
- Other factors prevent an equal time opportunity for infiltration.

Figure A illustrates the 'non-uniformity' in depths of water V_x applied to a sample level basin. The average depth of irrigation water furnished to the field is $V_f = 99.8$ mm, which is about equal to the measured inflow at the field inlet $V_f = 100$ mm.

In this example, there is no loss of water during transport from the field inlet to the place where it is applied, and all the water infiltrates into the cultivated soil. So, if the required V_m of the crop is 100 mm, Equation 1 would give a field application efficiency of $e_a = 100$ per cent.

Assuming that V_f should (almost) be equal to the required V_m, however, is contradictory to the definition of V_m: depth of water needed, and made available, for evapotranspiration by the crop to avoid undesirable water stress in the plants throughout the growing cycle. From Figure A then it is evident that some parts of the basin do not receive the necessary 100 mm. In fact, striving for an e_a value of 100 per cent causes

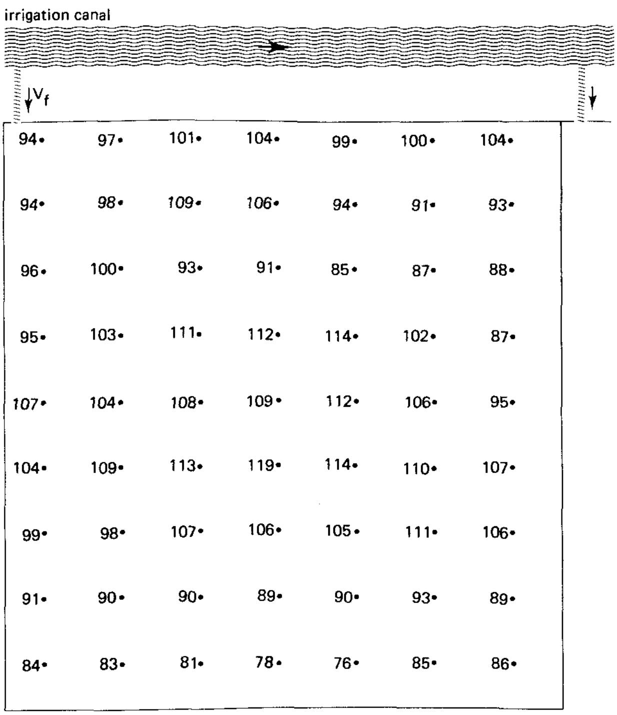

Figure A Illustration of the uniformity of field water application under irrigation (up to 24 mm too little) in half of the field. The other half of the field receives too much water, which, if more water is applied than can be stored within the rootzone, causes local recharge of the groundwater basin.

The above example illustrates why e_a, as defined, cannot be 100 per cent and why it is necessary to take into account the uniformity of water application. We cannot be sure that a system is well managed until we compare the measured e_a-value with the target value (see Section 5). The problem of selecting the degree of uniformity of application is determined mainly by a benefit versus cost analysis. The latter is beyond the scope of this paper.

3 Uniformity and the application method

Each water application method presents different problems in measuring and taking into account the uniformity of water application. In this context the application methods will be reviewed first, after which a statistical technique will be presented so that the application uniformity of different methods can be compared.

3.1 Localized irrigation

Drip, trickle, and other forms of localized irrigation do not apply water to the total field surface. These techniques are mainly used on tree plantations where there is usually one or more water emitter per plant and on row crops where one emitter may serve several plants. In water application studies it is often assumed that all water applied from one or from a group of emitters is available to the corresponding plant.

Uniformity of water application is basically determined by the flow rate of each emitter. This flow rate is influenced by:
- Hydraulic design of the pipeline system and related variations in water pressure in the emitters;
- Deviation in manufacturing dimensions of the emitters;
- Clogging and mechanical damage to the emitters;
- Maintenance of the system and replacement of non-functioning emitters.

The influence of these factors can be controlled to a certain extent. For instance, the hydraulic design of the pipeline system and related devices can be such that the pressure in individual emitters varies less than $\pm$ 10 per cent from the average pressure.
Volume/depth of water applied is directly related to the soil water depletion. The flow rate from the emitter (or group of emitters serving one plant) is a good measurement of the uniformity of water application. This concept was reviewed by Howell et al. (1980), who found the variation in emitter flow rates to be normally distributed.

3.2 Sprinkler irrigation

An important characteristic of sprinkler irrigation is that one nozzle usually applies water to a large area with many plants. Because of the regular layout of the field system, a repeating pattern of water application occurs. The amount of water that becomes available to a certain plant depends to some extent on the location of the plant within the repeating pattern. The ratio between the size of the plant and the size of the repeating pattern thus has a systematic effect on the uniformity of water application by sprinklers (Seginer 1979).

The uniformity of water application by sprinklers is commonly measured using a grid of sampling cans, each of which represents the same area. The distribution of the water caught in each can is recorded, and a picture emerges of the uniformity of water application in a particular irrigation turn.

This convenient method ignores three facts:
1. If the rate of application exceeds the local infiltration rate, surface flow occurs in depressions in the field;
2. Upon infiltration, the water in some soils moves laterally (Cohen and Bressler 1967);
3. The plants themselves modify the uniformity of application.

A further variation in uniformity occurs between successive irrigation turns because of changes in the system's working pressure, wear in the nozzle openings, the vertical or non-vertical position of the nozzles, wind direction and force, nozzle clogging and replacement.

Together with the four factors mentioned under 'localized irrigation', which determine the flow from individual nozzles, we can see a rather independent application of water to the grid points of a field. The population of data on the actual amount of water applied can be used to express the uniformity of application independent of the mean application.

3.3 Surface methods of water application

The uniformity of water application in a field comprising one level basin, several border strips, or many furrows, depends to a great extent on the design and construction of the field system.

This includes the width and length of the field, the accuracy of basin-levelling, the grade of borders and furrows, the dimensions of furrows, water supply structures and/or canals, the flow rate to the field and individual borders or furrows, the duration of water application, and the design at the downstream end of borders or furrows.

A number of natural factors also influence the uniformity: the variation of infiltration rate through the field, a change of irrigated type of crops, the change in resistance to flow because of crop growth, soil tillage, and crusting of the field surface.

Further, there are operational factors which influence the uniformity of water application. The rate and duration of flow, the maintenance of the field canal, and stopping leakage from one field, border or furrow to the adjacent field, border, or furrow are all important.

The uniformity of application under each combination of these (independent) factors is usually determined by studying the opportunity time for water to infiltrate the soil at a grid point, or by measuring an increase in soil water storage.

4 Expressing uniformity of application

4.1 Introduction

To express the uniformity of water application we should examine a statistical technique for measuring the dispersion and mean of the application data collected at the grid points or at the emitters. There have been various attempts to do this. The normal and rectangular distributions and that of an incomplete gamma function have all been investigated (Hart and Heerman 1967; Arya and Narda 1975; Seginer 1981; and Karmeli 1978). The normal distribution implies that the variate is distributed from minus infinity to plus infinity, but the latter two distributions are bounded on both sides. The mean deviation (Christiansen 1942) and the simple ratio of max./min. depth applied (Culver and Sinker 1966) also are used. The two latter methods imply no particular statistical model of the frequency distribution.

In Section 3, it was shown that the water applied to grid points (or emitters) is a function of many factors. Some of these factors cause a normal distribution of the applied water; others have a different frequency distribution. Because of the number of factors involved, in this paper we assume a normal distribution of water applied to the grid points. Although this assumption is not entirely correct, it enables us to compare the uniformity of water application by different irrigation methods.

4.2 Normal distribution of depth of applied water

Data with a normal distribution can be presented in dimensionless values. On the vertical axis of Figure B we plot $\Sigma(V_{x,f}/V_f)$ as a per cent, where $V_{x,f}$ is the depth (in mm) of water applied to the field at a given grid point. On the horizontal axis we plot standard deviation units with zero mean. The result is a cumulative frequency curve for the normal distribution (see the lefthand curve of Figure B).

If the mean depth of irrigation water furnished to the field equals the depth of water needed for evapotranspiration by the crop, this means that half of the field will receive more water than needed, while the other half will not. This is illustrated by the lefthand curve in Figure B.
The mean field application can be increased, which will reduce the area that is under-irrigated. How much this application is to be increased depends on how great a portion of the field is allowed to be under-irrigated. In other words, the target value for the mean depth of water furnished to the field $V_{f,target}$ equals

$$V_{f,target} = V_m + sT_p \tag{2}$$

where

- s = standard deviation of the depths of the water applied to the field at given grid points (mm)
- T_p = the value that is exceeded by a random variable, normally distributed with zero mean and standard deviation units, with the probability P

Values of T_p as a function of P can be read from statistical handbooks or from Table A.

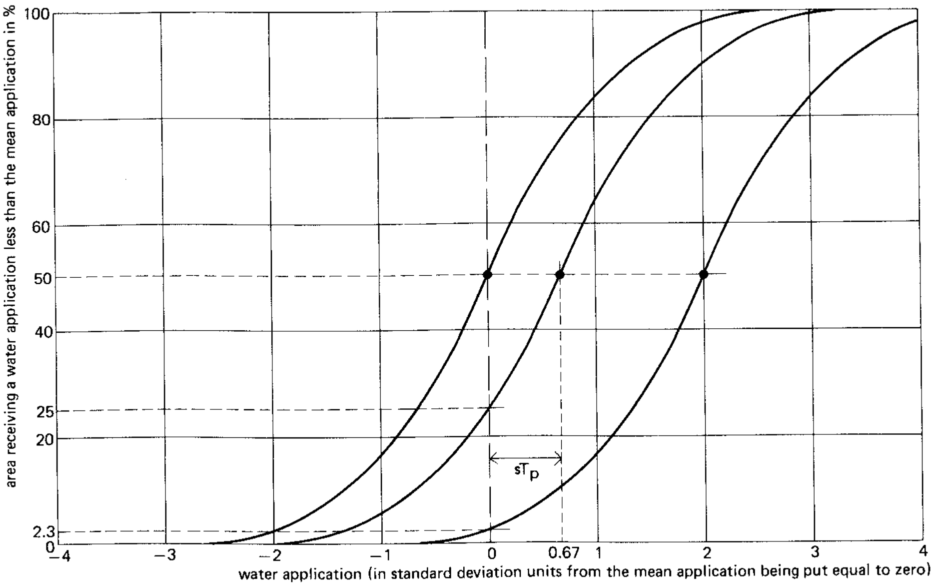

Figure B For a normal distribution; the relationship between the mean application and the percentage of an area receiving less than the mean

Table A Percentage points of the normal distribution

P	T_p	P	T_p	P	T_p	P	T_p	P	T_p
50	0.00	5.0	1.64	3.0	1.88	2.0	2.05	1.0	2.33
45	0.13	4.8	1.66	2.9	1.90	1.9	2.07	0.9	2.37
40	0.25	4.6	1.68	2.8	1.91	1.8	2.10	0.8	2.41
35	0.39	4.4	1.71	2.7	1.93	1.7	2.12	0.7	2.46
30	0.52	4.2	1.73	2.6	1.94	1.6	2.14	0.6	2.51
25	0.67	4.0	1.75	2.5	1.96	1.5	2.17	0.5	2.58
20	0.84	3.8	1.77	2.4	1.98	1.4	2.20	0.4	2.65
15	1.04	3.6	1.80	2.3	2.00	1.3	2.23	0.3	2.75
10	1.28	3.4	1.82	2.2	2.01	1.2	2.26	0.2	2.88
05	1.64	3.2	1.85	2.1	2.03	1.1	2.29	0.1	3.09

Combining Equations 1 and 2 shows that the target value for the field application efficiency because of non-uniform water application is

$$e_{a,target} = \frac{100\ V_m}{V_m + sT_p} \text{ per cent} \qquad (3)$$

The uniformity of water application is sufficiently characterized by either this target efficiency or by the standard deviation of $V_{x,f}$. It should be realized that this standard deviation may vary through the growing cycle. For several application methods it may also be a function of the mean depth of water applied. We recommend research on the uniformity of the commonly used water application methods.

4.3 Example

The above method can be applied to a given situation to calculate either the field application efficiency (actual and target), or the probability P, i.e. the percentage of the field that is being under-irrigated. The latter is an estimate of the quality of irrigation.

Given:
A level basin is irrigated in such a way that s = 10.6 mm. The required depth V_m = 80 mm and the V_f = 100 mm (see Figure A).

Question 1
What is the target value for the field application efficiency if we allow under-irrigation in 25 per cent of the area of a field (low 1/4 of the area)?
From Table A we read for P = 25 per cent of a T_p value of 0.67. Substitution of T_p and s into Equation 3 yields

$$e_{a,target} = \frac{100 \times 80}{80 + 10.64 \times 0.67}$$

$$e_{a,target} \simeq 92 \text{ per cent}$$

and

$$V_{f,target} = \frac{100\, V_m}{e_{a,target}} \simeq 87 \text{ mm}$$

In this example, the irrigator could thus improve his field application efficiency by reducing the V_f value.

Question 2
What is the quality of irrigation when V_f = 100 mm and V_m = 80 mm? Substituting all known variables into Equation 2 gives

$$100 = 80 + 10.64\, T_p$$

$$T_p = 1.88$$

Entering Table A with this value gives P = 3 per cent. Hence, only 3 per cent of the (level basin) field receives less than the needed V_m = 80 mm.
Comparing the two irrigations above will now yield some very interesting results (assuming the same V_m = 80 mm):
- If V_f = 87 mm, then e_a = 92 per cent. This is good, but only 75 per cent of the field is well irrigated, i.e. receives more than it needs;
- If V_f = 100 mm (15 per cent more of the water used, with a longer irrigation duration), then e_a = 80 per cent. This is less good, but now 97 per cent of the field is well irrigated;

For normal irrigation conditions we recommend that P be set at 25 per cent, so meaning that $T_p = 0.67$ should be used in Equation 3.

5 Other limitations to the target field application efficiency

Uses of irrigation water other than matching the crop evapotranspiration are leaching, frost control, cooling, nutrient and pesticide application, matching seepage losses (rice), weed control, soil tillage, and so on. Some people prefer to determine the field water requirement ($V_{f,target}$) by adding the above water uses to the required value of V_m. We do not recommend this practice because water applied to meet ET can usually meet one or more of the above 'other uses'. We can illustrate this point by expanding upon the above example.

Let us assume that $V_m = 80$ mm and that the 'leaching requirement' equals 7 mm for the related irrigation run. The irrigator thus sets his $V_{f,target}$ to 87 mm. The related $e_{a,target}$ is

$$e_{a,target} = \frac{100\ V_m}{V_{f,target}} = 92 \text{ per cent}$$

The example in Section 4.3 showed, however, that with this $V_{f,target}$ the low 1/4 of the field was under-irrigated (P = 25 per cent).
In this 25 per cent of the field obviously no salts are leached at all, which may result in a salinity problem. To cure this problem, the irrigator tends to increase the depth of water furnished to the field; for example, he increases his target to $V_{f,target} \simeq 100$ mm (see Figure A). Substituting of s = 10.6 mm and the above values for V_m and $V_{f,target}$ into equation 2 gives

$$100 = 80 + 10.6\ T_p$$
$$T_p = 1.88$$

Entering Table A with this T_p-value results in P = 3 per cent. Hence, even though 20 mm more water has been given for 'leaching' 3 per cent of the field may still have a salinity build-up.

Statistically, it is not feasible to increase the V_f value until the entire field is sufficiently leached. We need a practical limit. Let us use $T_p = 2$ (P $\simeq$ 2.25 per cent), so that the target value for the depth of water furnished to the field to fulfil leaching requirements is

$$V_{f,leaching} = V_m + 2s \quad (4)$$

The related field application efficiency then equals

$$e_{a,leaching} = \frac{100\ V_m}{V_m + 2\ s} \quad (5)$$

In our example, these values would equal

$$V_{f,leaching} = 101 \text{ mm (target)}$$

and

$$e_{a,leaching} = 79 \text{ per cent (target)}$$

Equations 4 and 5 clearly show that the field water requirement can only be reduced by reducing the standard deviation of the $V_{x,f}$ data; in other words, by improving the uniformity of water applications.

6 Conclusions and recommendations

In evaluating the field application efficiency, we recommend taking the uniformity of the water application into account.

A high field application efficiency may indicate a poor quality of irrigation in the sense that the water requirements of many plants in a given field may not be met. The application efficiency must be compared with the target efficiency (Equation 3). Under normal irrigation conditions, we recommend that P = 25 per cent ($T_p = 0.67$ in Equation 3). If leaching is required, the probability P is reduced to 2.3 per cent ($T_p = 2{,}0$ as shown in Equation 5).

This discussion paper assumes a normal distribution of irrigation water over the entire field. It may be questioned whether or not this distribution applies to all water application systems in combination with all fields. It would be interesting to gather data on actual application to verify their (normal) distribution for various application systems.

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APPENDIX V
EFFICIENCY RELATED TERMS

The technical efficiencies of irrigation water use are related to the movement of water through an irrigation system. This movement of water through an irrigation system, from its source to the crop, can be regarded as three separate operations: conveyance, distribution, and field application (Bos and Nugteren 1978; Bos 1980a).

Conveyance
The movement of water from its source through the main and sublateral or secondary canals or conduits to the tertiary offtakes.

Distribution
The movement of water through the tertiary (distributary) and quaternary (farm) canals or conduits to the field inlet.

Field Application
The movement of water from the field inlet through the field system and the application method to the crop.

To clarify these three terms, the terminology used for irrigation units, water supply canals or conduits, and related structures is defined in the following and is presented schematically in Figure C.

Quaternary Unit of Block
Area that can be irrigated efficiently by one man if he were to receive a continuous flow through a discharge measurement structure. (Note: in reality water will be used by more persons.)

Tertiary Unit
Area in which two or more quaternary units are grouped, and that receives water from the conveyance system through one offtake structure.

Lateral or Secondary Unit
Area in which two or more tertiary units are grouped, and which receives water from a canal or conduit through one (division) structure.

Sublateral or Sub-Secondary Unit
Similar to a lateral or secondary unit but supplied with water from a sub-lateral.

Irrigable or Project Area
Area where the technical facilities are available for irrigation, and to which water is supplied from the (surface) water source through one diversion structure.

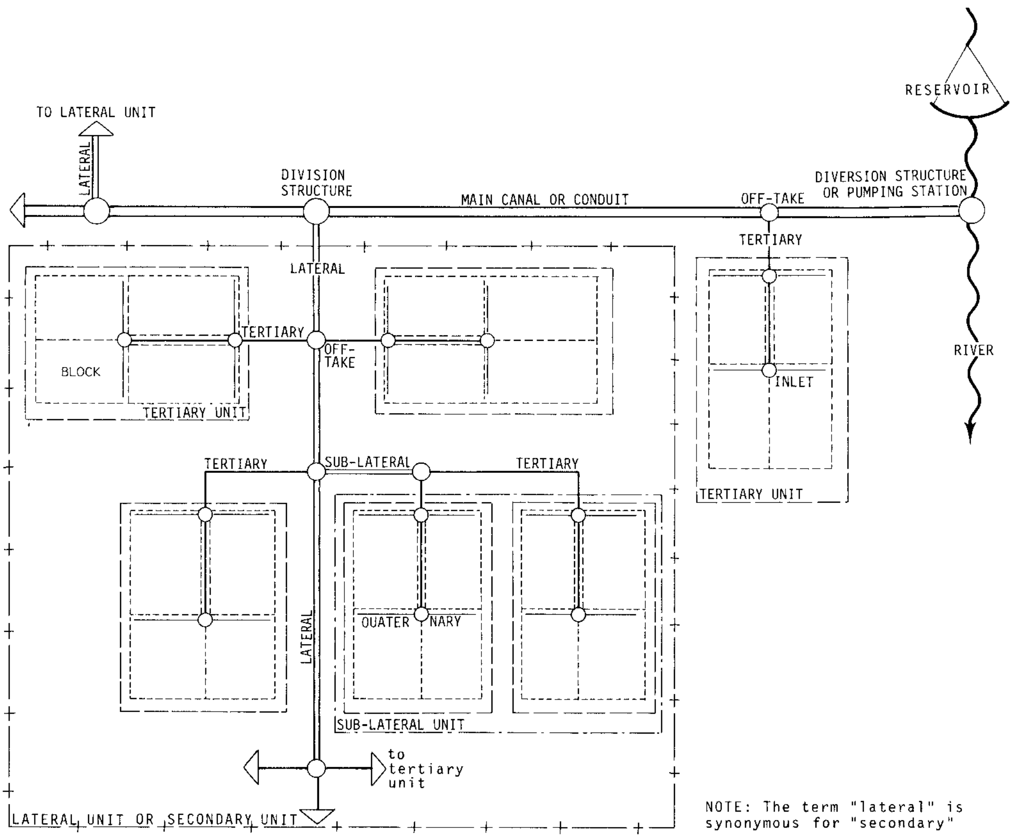

Figure C Schematical presention of terminology

Main Canal or Main Line
Canal or conduit taking water from the source of supply and conveying it to at least two laterals (or one lateral and one distributary/tertiary canal).

Lateral or Secondary
Canal or conduit conveying water to two or more tertiary units (or one tertiary unit and one block). Normally, the lateral or secondary takes water from the main.

Sub-Lateral
Similar to a lateral but taking water from a lateral.

Distributary or Tertiary
Canal or conduit taking water from the conveyance system and supplying it to one tertiary unit. Normally, the distributary or tertiary is the first-order canal or conduit from which the irrigator is allowed to draw water.

Quaternary or Farm Canal (Conduit)
Canal (or conduit), usually taking water from a distributary, and supplying it to one or more farms or fields. Together, these fields form one block.

Diversion Structure
The structure that diverts water from the water source and supplies it to the irrigable area.

Division Structure
A structure in the conveyance system that divides the flow over two or more conveyance canals or conduits, or both.

Offtake, Inlet, Turnout, or Outlet
A structure that diverts water from a conveyance or distribution system to a transporting system from which the irrigator is allowed to draw water. Depending on the area irrigated from the structure, the following terminology is used:
- Tertiary offtake: a structure that diverts water from a main canal or pipeline or lateral (sublateral) to supply one tertiary unit;
- Group inlet: a structure that supplies water to a block in which different farmers use the flow in rotation;
- Farm inlet: a structure that supplies water to one farm;
- Field inlet: a structure that supplies water to one field.

The preceding definitions may sometimes still leave room for doubt, i.e. it may be difficult to decide whether a certain canal or conduit belongs to the conveyance or to the distribution system. In such cases it is recommended that the organizational setup of the water supply be considered. It can then be decided at which point the control of water is turned over from the water supply organization to the individual or collective water users. Downstream of this point, the canals or conduits are part of the distribution system.

If a farm receives its supply directly from a main or lateral canal or conduit that is under the control of the water supply organization, the distribution system will begin immediately downstream of the farm inlet. If water is supplied to a group of farms, the distribution system begins immediately downstream of the group inlet. If the irrigated area under supply is immediately downstream of the (group) inlet that supplies the water to a number of individual fields. Beginning at these points of supply, the distribution system continues until the field inlets are reached.

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