Design and operation of irrigation systems for smallholder agriculture in South Asia

FAO INVESTMENT CENTRE TECHNICAL PAPER

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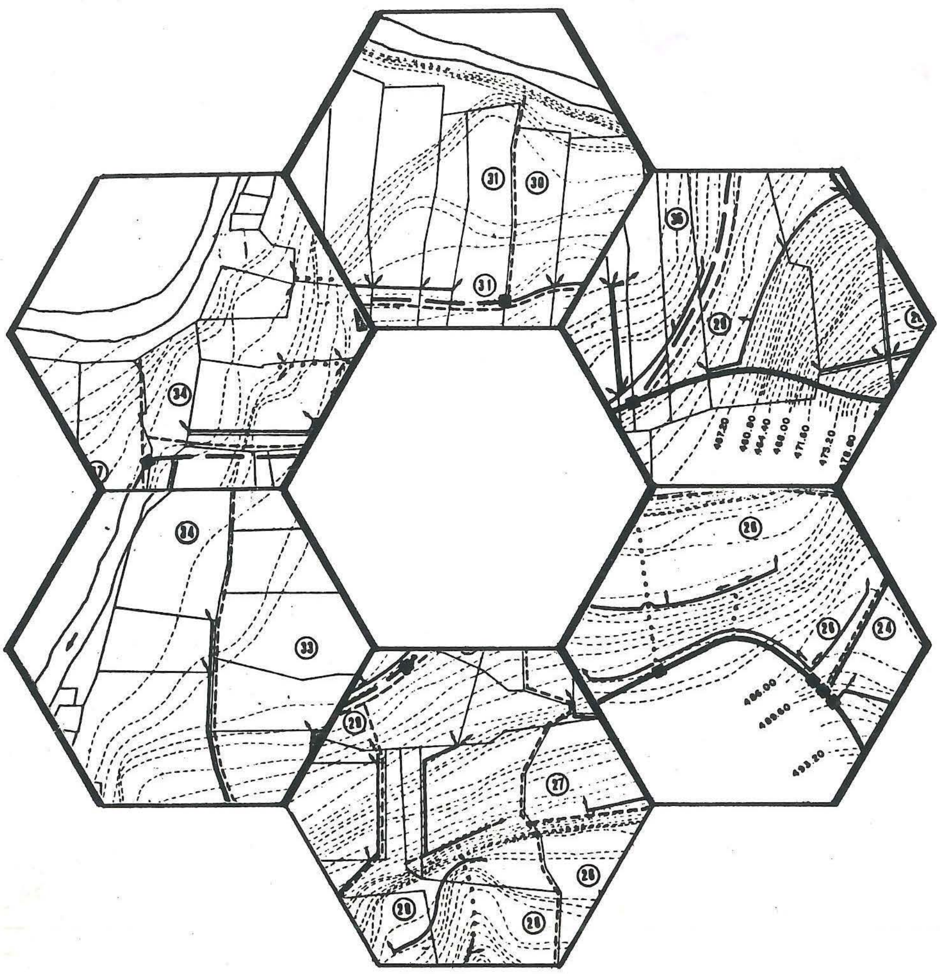

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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by
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FOREWORD

The FAO Investment Centre's principal function is to assist member countries in the preparation of agricultural and rural development projects for international, and sometimes local, financing. The Investment Centre is also acknowledged as a source of assistance in the development of national capacities for project preparation and execution.

Over the last 15 years, irrigation has occupied a very important position in international lending for development and has made a considerable contribution to increased agricultural production. There are, nevertheless, a number of problems in smallholder irrigation which continue to limit the rate of effective implementation of such projects and occupy much of the attention of development agencies in this field. Some of the problems are technical, but more often they relate to the small cultivator and his role in the operation of the project and the development of the irrigated area.

This FAO Investment Centre Technical Paper comprises 5 papers selected from more than 30 prepared between 1974 and 1985 for the assistance of Irrigation Department staff, mainly engineers, preparing and executing projects in India assisted by the World Bank. Although these papers were written for projects in India, the principles involved apply in neighbouring countries and further afield. However, when transposing costs to another region, account should be taken of the comparatively low cost of construction in India.

Since I believe that the papers could be of considerable use to people outside the Investment Centre who share our interest in the development of irrigation projects, I have decided to give them wider circulation by publishing them as part of our series of Technical Papers. The opinions expressed, however, remain those of the author and are not necessarily endorsed by the Organization or the Bank.

Any comments on the material or suggestions which could contribute to the greater usefulness of the paper would be most welcome and should be addressed to the Investment Centre.

Cedric Fernando
Director
FAO Investment Centre

DESIGN AND OPERATION OF IRRIGATION SYSTEMS FOR SMALLHOLDER AGRICULTURE IN SOUTH ASIA

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PAPER A

ISSUES AND OPTIONS IN DESIGN OF RESERVOIR AND CANAL SYSTEM

A. ISSUES AND OPTIONS IN DESIGN OF RESERVOIR AND CANAL SYSTEMS

A.1 INTRODUCTION

Scope

A.1.1 In the formulation of projects for irrigation of smallholdings in South Asia there are a number of questions relating to water allocation and distribution which arise very frequently. They include economic and sociological issues, as well as technical. In the following paper project design is discussed with particular regard to these issues. The paper does not provide comprehensive coverage of irrigation system design, but focusses on key issues and options, consideration of which is basic to project formulation. The paper is intended for both administrative and technical readers.

A.1.2 Conditions typical of the area under discussion are a monsoonal climate with average annual rainfall in the range 750 to 1,500 mm, and holdings generally from 0.5 to 5 ha, principally owner-cultivated.

A.1.3 The paper refers to gravity irrigation from surface supply (river or reservoir). Tubewell and river-lift irrigation are dealt with in Volume II.

Background. Objectives in Irrigation System Design

A.1.4 Objectives may include any or all of the following, with priority varying from one project to another.

a) Maximum production of one or more crops.

b) Maximum flexibility for irrigating a wide range of crops.

c) Equity in water distribution, between cultivators.

d) Simplicity of operational scheduling.

e) Ability of system to respond to a wide range in seasonal water availability, or in day-to-day demand.

f) Minimum operating and maintenance costs, including cost of staff.

g) Efficiency of delivery from minor canal to field.

h) Acceptable capital cost.

i) Favourable reaction of cultivators to system proposed.

j) Non-susceptibility to interference with structures, or illegal operation by cultivators.

A.1.5 Not all of the above objectives are mutually compatible: the objective of flexibility and efficiency of delivery may call for a system involving greater susceptibility to tampering with structures or mis-operation. On the other hand a system with few controls and consequently little flexibility of operation may be a decided constraint on future diversification of irrigated agriculture. A further example is the conflict between the objective of equity of water distribution in an irrigation area and the interests of particular groups or individuals. This can be a particular problem with improvement projects, where an improvement to distribution within a command as a whole usually implies a reduction of supply to those cultivators who have been taking more than their fair share in the past, with likelihood of resistance on their part. Conflict between the design objectives of an irrigation project and the aspirations of the cultivators served by it may also be encountered with new projects, particularly those intentionally designed to distribute a limited amount of water over a relatively large area. In this situation Government may make a decision, on grounds of social equity, to provide a large number of cultivators with a limited amount of irrigation, rather than full irrigation to a smaller number. Problems commonly encountered in such circumstances include:

- Cultivators consider that the amounts of water supplied to them are inadequate and, where possible, upstream cultivators may manipulate the system to provide themselves with more at the expense of downstream cultivators.

- The type of crop on which the design of the system has been based (minimizing water requirements and hence providing for an acceptable irrigation intensity) may not be of interest to cultivators as an irrigated crop. They may only be interested in higher water-use crops (e.g. sugarcane) with higher returns per unit of area cultivated. This aggravates the problem of illegal upstream diversion.

- Efforts of the Irrigation Department to simplify the operational problem of fairly distributing the limited supply of water, by restricting service under each distributor to one season only or by other means, frequently meet with considerable resistance. The resistance can be highly organized politically.

A.1.6 The problem of cultivator resistance to regulation of supply, and manipulation or removal of control structures, is widespread. It is a central consideration in the design of irrigation systems and of irrigation improvement projects. The motivation of the individual cultivator, or group, is understandable. Nevertheless the actions are usually contrary to public interest and the interests of other cultivators in the area. The remedies, to the extent that remedy is possible, are likely to include:

- Avoidance of situations which are likely to encounter strong cultivator resistance, as far as this is possible.

- Providing sufficient Irrigation Department staff for operation or supervision of a system, and adequate funds for maintenance. This is not easily accomplished, in view of perennial financial stringency. The converse course is to design the system with due recognition of the limited operational staff likely to be available.

- Recognition of the fact that some degree of misuse and damage to structures is inevitable, and designing them with a view to their resistance to damage or tampering.

- Providing Irrigation Department staff with legal powers sufficient to police the irrigation system.

- Providing legal backing to operation of the system, including support to rights of individual cultivators. (These last two items are likely to be difficult to ensure, and to make effective, where sectional groups of cultivators have strong political weight.)

- Organizaton of cultivators to be self-policing. This is an admirable objective, but not easy to achieve in a large irrigation system where community of interest may not extend beyond the village.

A.1.7 The problems described, while common to many irrigation projects, are not universal. There are areas in which water distribution is well ordered, due either to a tradition of discipline among irrigators or to an adequate level of operational management by the Irrigation Department. On the other hand there are areas where the operation of large projects has deteriorated so far that there is little semblance of water management or control.

A.1.8 The problem, briefly, is the design of an irrigation system which can be operated effectively, having regard to the problem of maintaining order within the area and practical limitations in the extent of Departmental supervision and control which can be provided. While simplicity of design and operation is desirable, this should not be at the cost of efficiency in matching water delivery to agricultural needs. Projects constructed or improved should be designed with a view to likely agricultural developments over the next one or two decades, or should be capable of adaptation to such developments.

A.1.9 In the following discussion physical factors influencing the design of the system as a whole, such as reservoir capacity, design cropping pattern, and size of service area, are first considered. Operational factors including the allocation and scheduling of water deliveries to the cultivators and their implications in design of the canal conveyance and distribution system are discussed.

A.2 WATER SUPPLY AND DEMAND. DETERMINATION OF SIZE OF SERVICE AREA

Estimation of Project Inflows

A.2.1 The design of an irrigation system, particularly a large system, should preferably be based upon a long period of recorded river-flows. However the period of record available is often limited, and in the case of small projects on minor streams flow records may be entirely lacking. Derivation of inflows from rainfall or extrapolation of a short period of record by correlation with longer-term rainfall records may then be necessary. It is not within the scope of this paper to discuss techniques in estimation of runoff from rainfall, but it is emphasized that such estimation is very approximate, particularly in seasons of light precipitation, and should be backed up by initiation of actual flow recording as early as possible in the investigation of a project. Sophisticated statistical methods exist for generating a synthetic long-term series of flows from a shorter-term actual record, but such a series is also a considerable approximation. It is nevertheless convenient to have an indicative series of flows, even if quite approximate, as a means of examining the functioning of the system under a range of conditions. This is more informative than simply examining the "75% probable", or other, design year. However, the extent to which firm operating rules can be developed through a statistical approach is debated.

A.2.2 Estimation and correlation of runoff are necessarly approximate, and should not be credited with greater accuracy than they deserve.

Reservoir Storage and Seasonal Use of Water

A.2.3 In the conditions under discussion rainfall is monsoonal, the remainder of the year being relatively dry. The stream-flow in the monsoon season may be used for supplemental irrigation of a monsoon crop or stored for use in the dry season, if there is a suitable site for a storage reservoir. Other factors to be considered are the unit cost of storage at the site, and whether or not storage should be used partly for carry-over from one year to the beginning of the next (for pre-monsoon irrigation) or for regulation over longer periods.

A.2.4 With regard to choice of wet-season or dry-season crops, cultivators are likely to indicate preference for monsoon season paddy (if irrigation of this crop is required). This may or may not be the desirable crop in the broader economic view, or in the interests of the cultivators as a group if there is insufficient water for paddy over the whole service area. 1/

A.2.5 Carry-over of storage to permit pre-monsoon irrigation and earlier planting of monsoon season crops (e.g. paddy or sorghum) may be for the purpose of achieving more effective use of rainfall in that season, or to permit earlier harvesting of the monsoon season crop and hence earlier planting of the following post-monsoon crop (a particular advantage for wheat). However, with some soils which are difficult to handle when wet, cultivators may prefer to leave fields under rainfed crops in the monsoon season and to use irrigation for dry-season or hot-weather crops.

1/ The question of paddy vs non-paddy, and the situation of the individual cultivator where choice is left to him is discussed further in Paper C, "Irrigation from Small Tanks", in this Volume.

A.2.6 It is evident from the above discussion that the manner in which reservoir storage will be used is not entirely predictable at the time of project design. As discussed later, cropping patterns and seasonal choice of crops may change radically with time, affecting reservoir operation and storage needs.

A.2.7 The remaining factor influencing choice of storage capacity is its cost. Topography and geology may or may not be favourable to dam construction or storage at a particular site. High cost of storage can be a constraint on the capacity provided for a particular project, and consequently on the use of water for monsoon vs dry-season irrigation. On the other hand at a more favourable site a relatively large amount of storage capacity may be provided, permitting considerable flexibility in future seasonal water use.

A.2.8 To summarize, choice of reservoir storage capacity for a particular project requires consideration of anticipated seasonal distribution of water use and possible variations in distribution, also of unit cost (particularly incremental cost) of storage at that site, rather than basing it simply upon a standard proportion of annual runoff.

Significance of the "Design" Cropping Pattern. Possible Future Changes in Cropping Pattern

A.2.9 The design cropping pattern used in project formulation is usually based upon assessment of the suitability of the soils and climate of the project area for various crops, their marketability, and the prevailing Government priorities regarding crop production. However, as full development of an irrigated area is likely to be reached ten years or more after formulation of designs there is ample time in the interim for radical changes in relative demand for various crops and for new crops to appear in the area; this process of change is likely to continue in subsequent years. Furthermore cultivator preferences regarding crops may prove to be significantly different from Departmental projections or recommendations. The changes from the design cropping pattern which have been experienced in some recent large projects have been quite major, including from cool-weather to hot-weather irrigated crops, and from seasonals to perennials.

A.2.10 Although a project may eventually adopt a cropping pattern considerably different from that originally projected, a nominal design cropping pattern is nevertheless a necessary feature of project formulation and analysis. Variations from the nominal pattern must, however, be considered. From the technical viewpoint factors which may be influenced by variation in assumed cropping pattern include peak capacity required in the canal system and reservoir capacity. Another related issue is the question of whether differences in cropping pattern within the project area will be catered to in operation of the system, and how far down (to the minor canal?) such differentiation will be considered.

A.2.11 Distinction should be made between variations in cropping pattern which would influence the physical features of the system (such as canal capacity) and variations which influence the method of operation only (such as scheduling of irrigation releases). The system as constructed should be capable of accommodating as wide a range of cropping patterns and operational practices as is reasonably possible.

Crop Water Requirements and Crop-Water Response. Sub-Optimal Irrigation

A.2.12 Crop water requirements are usually defined as the amount of water which a particular crop would use consumptively if not under significant soil-moisture stress, at the stage of growth at the time, and under the prevailing climatic conditions in the location in question. This is the "optimum" consumptive use, in the sense that growth is not constrained by lack of water. It does not necessarily reflect the optimum use of water from the economic viewpoint.

A.2.13 The consumptive requirement of a crop as so defined is not a value which can be precisely estimated, or measured with great precision. Comparison of estimates by reputable methods, and lysimeter measurements, indicates a range of at least ± 20% in values. 1/ The "Modified Penman" method (described in FAO Irrigation and Drainage Paper 24, "Crop Water Requirements") is supported by a large amount of field data, and is now widely used in project preparation for international lending institutions. However, even in the most favourable circumstances there remains a "level of uncertainty" of at least 10 to 15% in estimation of consumptive requirements at the plant. To this must be added the approximation inherent in estimation of field application efficiency. Finally, there is the question of whether, in any case, it is economically appropriate to apply the "optimum" quantity of water to a crop under the supply conditions of the particular project. In many cases it is not. Data on the relationship between crop yield and proportion of "optimum" water actually applied indicates that for most crops (but not all) crop yield per unit volume of water is at a maximum when application of water is considerably less than "optimum". 2/ Timing of water applications to coincide with periods of particular physiological need (critical stages of growth) can be of more importance than seasonal total. "Sub-optimal" water application may also be a major advantage from the viewpoint of control of waterlogging, deep-rooted crops (such as sugarcane) then being encouraged to draw upon and lower the water-table.

A.2.14 In the circumstances, the results of crop tests at agricultural stations in or near the project area are probably the best indication of desirable water use. Furthermore the data so provided is in terms of irrigation requirement at the field boundary. This includes field losses and renders separate estimation of such losses unnecessary.

A.2.15 Calculated "optimum" values of consumptive use are nevertheless of value as a reference point, and as a means of extrapolation from one area to another, particularly when crop-use data is not available in the immediate vicinity of a project and reference has to be made to an agricultural station further afield.

1/ The 1974 report of the ASCE Technical Committee on Irrigation Water Requirements, based on an exhaustive comparison of methods of estimation then in use, and results of actual field measurements, showed very wide variations (± 30% or more).

2/ See FAO Irrigation and Drainage Paper 33, "Yield Response to Water", 1979. The term "application intensity" is used herein to convey the percentage of "optimum" actually used.

A.2.16 Nominally the calculated irrigation requirement at the field boundary covers consumptive use at the plant less effective rainfall, field losses, infiltration (in the case of paddy), and in some situations a leaching component. The latter is not normally provided for in a monsoonal climate as wet-season rainfall provides leaching; in any case field losses function partially to provide leaching.

A.2.17 Estimation of the effectve contribution of rainfall to crop water requirements, and more significantly to reduction in irrigation requirements, is a contentious subject. The USDA method of estimation of effective rainfall contribution described in FAO Irrigation and Drainage Paper 24 takes into account the ratio of monthly consumptive requirement to monthly precipitation. The greater the consumptive demand the greater the proportionate effectiveness of rainfall in contributing to demand.

A.2.18 This is a logical approach to estimation of effective rainfall in rainfed situation. Under irrigation, however, the situation is less simple. Rainfall may occur immediately after irrigation when the soil is already saturated, in which case it will largely be lost as runoff. Or it may occur when irrigation supply is already committed in the canal system and cannot be withheld. Hence the effectiveness of rainfall in reducing irrigation supply is likely to be less than its effectiveness under non-irrigated conditions, to an extent influenced by the degree of control provided in the operation of the canal system. Due to this uncertainty an arbitrary assumption of "50% effectiveness of 75% probable rainfall" is often used in estimating rainfall contribution under irrigation. This is probably appropriate when irrigation is the primary source of water, and rainfall is the supplement. In the reverse situation, however, when irrigation supplements rainfall, for instance providing a single pre- or post-monsoon irrigation, or irrigation in the event of a gap in the monsoon, the latter approach could considerably under-estimate the seasonal effective rainfall, and over-estimate the irrigation requirement. A rational approach tailored to each particular situation is indicated, rather than a rule-of-thumb generalization.

A.2.19 A further much-debated topic is the amount of water required for irrigation of paddy. Issues include:

- Cultivation and planting practices.

- The amount of water required for pre-cultivation and puddling.

- The rate of infiltration from the flooded paddy field.

- The extent to which irrigation requirements can be reduced by permitting draw-down of standing water in the fields for part of the season.

A.2.20 Cultivation practices include dry-seeding, broadcasting of pre-germinated seed on a moist seed-bed, and finally transplanting into a puddled seed-bed. Cultivation in the latter case varies from a procedure in which the field is kept saturated for up to a month in the process of cultivation and puddling, to a two-day procedure in which puddling and transplanting follow almost immediately after ploughing. Practices are to some extent dictated by local circumstances; for instance a long period under saturation is inevitable if a large area (hundreds of hectares) is to be puddled by field-to-field flow from a single point of delivery. The total amount of water required for land preparation and puddling up to the stage of transplanting varies from 180 to 350 mm, depending upon the practices actually employed.

A.2.21 The rate of infiltration from a flooded paddy field is influenced by soil permeability (including the effect of puddling), and by constraints on internal drainage. The effect of the latter can be difficult to estimate, but it may be the controlling factor. As an instance, paddy is being grown in some areas on highly permeable sands with virtually no infiltration because the water-table is almost at the surface. Measurement of infiltration rate by conventional ring infiltrometer would give a very misleading result in such circumstances. In other situations infiltration from an upper paddy field simply re-appears as supply to a lower field.

A.2.22 Actual consumptive use by the paddy may be the least component of the water requirement, being exceeded by infiltration. The latter may be reduced in part by allowing the imponded water to draw down until the soil is at field moisture capacity, thereby reducing the seepage gradient. However, this can only be done at certain periods in the growing season if yields are not to suffer. Further, such draw-down may require introduction of chemical weed-control. A reduction of water requirement of some 15% can nevertheless be obtained by this means.

A.2.23 Cultivation practices, soil type and sub-surface drainage conditions specific to each site should be taken into account in projecting irrigation requirements.

Irrigation Intensity and Determination of Size of Service Area

A.2.24 Given the quantity of water available in an average year, the capacity of the reservoir and the proportion of the various crops to be grown, it is possible to calculate the size of service area (the "nominal" area) which could be given full irrigation in the season of maximum water use. This is the minimum size of service area required if the available water is to be fully utilized, with the crops proposed. It is not necessarily the most desirable size of service area, which could be considerably greater.

A.2.25 There are reasons for making the service area larger. It may not be possible to plant the second season crop (or some components of it) in the same field as was occupied by the first season crop, for reasons of time required for cultivation, over-lap of harvesting and planting dates, etc. Of perhaps more importance may be the sociological consideration of sharing the benefits of irrigation to as wide a group of cultivators as possible. However, sharing the benefits more widely implies reducing the amount of water available per unit of area, and therefore reducing the proportion of the area under irrigation in the peak season to less than 100%. Up to a certain point this reduction may have economic and technical advantage. Rotational fallow may be introduced; with lesser water application per unit of area waterlogging may be less of a hazard. Furthermore a cultivator faced with less water than required to give "optimum" irrigation to 100% of his holding normally has the choice of either giving optimum irrigation to a lesser percentage of his land, or adopting a reduced application intensity over a greater percentage. The latter is likely to be his choice (if this option is left to him) with possibility of increased crop production per unit volume of water, if this philosophy is not carried too far. Beyond a certain point, however, further increasing the size of the service area increases the cost of the canal system and land shaping for irrigation without commensurate advantage, unless it be on social grounds.

A.2.26 A criterion which has been used in some areas, in defining a lower limit to the size of service area, is that cultivators should not be provided with canal water for more than 140% <u>annual</u> intensity of irrigated crop (i.e. the sum of the areas under irrigation in the two seasons, divided by the service area). Criteria for the upper limit of area have not been defined. An annual intensity of irrigated crop of 100% (sum of the two seasons) might be considered as stretching the supply of water as far as is reasonable, but in some drought-prone areas systems have been designed for still lower annual intensities. This is a question of Government social policy. The intensity of irrigated crop is not an entirely satisfactory measure of the extent of service provided, as a cultivator may use the amount of water provided to give relatively heavy irrigation to a small proportion of his holding, or relatively light irrigation to a larger proportion. Thus, the annual irrigation intensity achieved does not necessarily indicate the amount of irrigation received. A better indicator is the volume of water provided per hectare either annually or for a particular season. This translates to a depth of water calculated over the whole of the service area (or of the holding) either annually or seasonally.

A.2.27 Confusion may be caused in project descriptions by lack of clear distinction between:

a) The area of an irrigated crop expressed as a percentage <u>of the area of all irrigated crops</u> seasonally or annually. This is the "irrigated crop percentage", and;

b) The area of an irrigated crop expressed as a percentage <u>of the total service area</u>. This is the "irrigation intensity" for that crop.

A.2.28 To illustrate, take the case of an 8 ha holding all of which is in command of an irrigation system in which 4 ha of irrigated sorghum are cultivated, followed by 6 ha of irrigated wheat. The total area of irrigated crop is 10 ha. The irrigated <u>crop percentages</u> are:

Sorghum	4/10		40%
Wheat	6/10		60%
		Total	100%

The <u>irrigation intensities</u> are:

Sorghum	4/8		50%
Wheat	6/8		75%
		Total	125%

A.2.29 In referring to an area already under irrigation, crop percentages can be derived directly from the figures for actual crop irrigation intensity simply by dividing each by the total irrigation intensity. However, in referring to a future project anticipated irrigation crop intensities (and project total) depend upon estimates of optimum consumptive use, application intensity (conventionally taken as 100% of optimum), and irrigation efficiency. As actual irrigation intensities may be substantially higher than anticipated, in describing a future project the anticipated crop percentages and the amount of water to be made available (volume per unit of service area, or equivalent depth) are more specific figures than anticipated irrigation intensities. They do not involve any assumption as to application intensity.

A.3 WATER DISTRIBUTION. ALLOCATION AND DELIVERY TO CULTIVATORS. CANAL SYSTEM OPERATION

Concepts in Design of the Distribution System. Response to Demand versus Scheduled Supply

A.3.1 In Chapter A.1, possible objectives in the design of an irrigation system were briefly discussed, and it was noted that not all such objectives were necessarily compatible, for instance simplicity of operation on the one hand and flexibility in meeting demands (particularly demands of individuals or groups) on the other. In fact much of the debate regarding the design and operation of irrigation systems in a smallholder environment centres on this question of the needs or desires of the cultivator, viewed against the constraints of operation of a major system.

A.3.2 The traditional approach to design has been to proceed from the primary canal system (and reservoir) down eventually arriving at the outlet supplying the group of cultivators. At the outlet the task of the Irrigation Department has been considered to be complete, the utilization of water beyond that point being the responsibility of others (the cultivator group or Agriculture Department, or Agricultural Extension). This view has recently changed, with responsibility for design of the watercourse system below the outlet devolving upon Irrigation Department (or Command Area Development Authority), preferably in consultation with cultivator groups. The organization of such cooperation in the design and management of irrigation systems is a subject in itself and is not pursued here, except to conclude that the cultivator is now regarded almost as the starting point rather than the end-point in irrigation system design. More specifically irrigation design now takes into account both the cultivator viewpoint, and technical constraints in design and operation of the delivery system. The resulting compromise is likely to be somewhere between the following two cases:

a) A limited demand system in which the individual cultivator may take delivery of his allocated seasonal share of water as and when he desires, subject only to certain physical limitations in distribution system capacity.

b) A system in which a schedule of deliveries is established at the beginning of each season, covering the project area as a whole or principal sub-divisions in it. The schedule is based on the principal class of crops to be given in that season and estimated requirements and availability of water. The cultivator adapts his operations to this schedule.

A.3.3 These two limiting cases are discussed before considering other solutions.

A.3.4 Case (a) represents the ultimate in freedom to the small independent cultivator. Allocation of a seasonal entitlement to water is presumed, as water is supplied at subsidized rates in most Asian public irrigation systems, and for reasons of equity the seasonal amount of water taken by the individual has to be controlled. Where this control is not exercised by scheduling of deliveries and the cultivator is free to take water when he wishes, as in this case, control or monitoring of the amount used requires some form of metering device at each holding, more specifically at each parcel of a holding where holdings are divided. 1/

A.3.5 While such a system is technically feasible, the following problems would have to be faced:

- Where individual meters have been used so far in Asia, tampering and removal have been very common. Rather than metering, water use could be calculated from the area of crop irrigated, but with less than satisfactory accuracy and no incentive for economy in water use.

- All canals, including watercourses would have to be designed with sufficient capacity to meet the collective demands of all cultivators at any time, subject to a reasonable diversity factor. This is not a problem with main canals, but it would be with watercourses, as it is desirable in the interests of efficiency of field application for each cultivator to take water at not less than a certain minimum rate (around 15 to 40 litres/sec), albeit for a short period of time, and the capacity of watercourse which would have to be provided would be large. Control of the rate at which each cultivator took water would have to be exercised by a device at each farm turn-out.

A.3.6 The above problems with Case (a) would be reduced if a small pond were to be provided at each holding (or sub-division of a holding) into which water were supplied at a more or less continuous small rate, and from which the cultivator could withdraw water whenever required. However, metering would still be involved. Furthermore in most topographic situations use of a pond would require pumping either into or out of the pond.

A.3.7 In view of the above difficulties the limited demand type of system of Case (a) is not generally considered for the individual smallholder. However, as discussed later, it may be applied more practically to a group of cultivators, also to a very small irrigation area such as a small "Tank" project.

1/ Unless regulation is left to the cultivator's conscience, which is not a practical solution in areas where water supply is limited.

A.3.8 Case (b) takes the opposite approach to Case (a). In the interests of simplicity of operation irrigation releases are scheduled so as to meet the needs of a pre-selected major crop or type of crop in the area, and the cultivators plan their cultivation, planting, irrigation, etc., to conform to this schedule of releases. Prerequisites for such a system are a predictable, well regulated supply of water, reasonably uniform soils throughout the service area, or division into a few discrete areas of different soil types, and preferably an alternative source of supplemental supply (e.g. small tubewells) for those cultivators who wish to differ radically from the pre-selected type of crop. The proviso regarding uniformity of soil type is necessary, as scheduling of deliveries is designed around a particular type of crop. A service area in which soils well suited to cultivation of cotton are interspersed with soils suited only to paddy (e.g. for drainage reasons) could not be irrigated effectively with a single "project" irrigation schedule. If the two soil types occurred in relatively large separate areas individual schedules could be worked out for each, but such a soil situation is the exception rather than the rule. This This is the problem encountered in the practice of "localizing" a project into areas suited to monsoon season irrigation or to dry season irrigation if the respective soil types occur in close proximity, intermixed in patchwork fashion. Even where soils are uniform there is usually a considerable range of crop possibilities, of widely differing type, with choice (if left to the cultivator) influenced by market conditions from year to year. Cultivator resistance may be encountered in imposing a "project" irrigation schedule when conditions clearly favour a particular type of crop.

A.3.9 However, as discussed earlier, distinction must be made between decisions which influence the design of the physical features of a system (canal capacity, etc.,) and those which are operational only and which may be modified if indicated by later experience. Case (b) is in the second category. It is an operational method which could be adopted with systems designed for more flexible scheduling, as described subsequently.

Methods of Allocation of Water, and Regulation of its Use

A.3.10 As is apparent from the discussion of Case (a) above, the basis of allocation and regulation of water use has a considerable influence on the design of the distribution system. In many older projects there is little attempt at formal allocation, and cultivators served by a watercourse take water as needed, or as available. The rate of supply to the individual cultivator may be very small, as several cultivators may divert from the watercourse at the same time. Supply to those at the downstream end of the watercourse system is precarious. Irrigation efficiency under these conditions is low.

A.3.11 New or modernized irrigation systems aim at more equitable sharing of water, and more efficient delivery. There are basically two types of allocation being practised. In one, entitlement to water is based purely upon area of holding. In the other it is determined through advance request by the cultivator each season, and agreement by the Irrigation Department for supply of sufficient water for a particular area of a particular crop. The Department exercises discretion in sharing the available supply between applicants. In both systems crop water charges are based on actual area of crop irrigated and type of crop.

A.3.12 The two systems have originated in very different situations, and both have merits in their respective areas. The first, based on area of holding, is adopted in north-western India where availability of water is limited. Strict economy in water use is practised by cultivators, and many supplement canal supply with small tubewells. The cultivator is free to use his allocation of water as he pleases, choice of crop, amount (depth) of water applied, and area irrigated being left to his judgement. This method of allocation has the merit of simplicity in water distribution and canal operation as flow required at any point is at the same rate per unit of area served throughout the system. The success of this method of water allocation is due in part to the uniformity of soils and topography (near flat) in the area in question, to the low canal irrigation intensities, and to the fact that supplemental groundwater is generally available.

A.3.13 The second system is practised under conditions of more variable soils and topography, where circumstances dictate growing different types of crop with differing water requirements, on neighbouring areas. Much of the later discussion of canal operation relates to this second situation and to various operational alternatives which may be adopted in this case.

Rate of Delivery of Water to the Cultivator. Rotational Supply. The Watercourse

A.3.14 A key requirement in water distribution to the small cultivator is delivery at a rate which he can handle effectively, with regard to farm channel conveyance and field application efficiency. This rate, the delivery stream, is likely to be between 15 and 40 litres/sec (in some cases higher), the rate depending upon length of farm channels, permeability and erodibility of soils, slopes, whether or not watercourses are lined, and to some extent on size of holding. 1/ It is not a sharply defined value, a range of ± 25% from nominal generally being acceptable (for instance from 15 to 25 litres/sec). This acceptable range in sizes of delivery stream is of considerable importance on design and operation of distribution systems, as will be apparent later.

A.3.15 It is evident that the water requirements of a holding of a few hectares could be supplied by such a delivery stream in a few hours once per week (or correspondingly longer once per fortnight). Supply is consequently rotated between neighbouring holdings served by a common channel. This channel could be of capacity two or three times that of the delivery stream, supplying two or three holdings simultaneously. This situation would, however, introduce the problem of how to divide the flow in such a channel equally between three holdings, and for different periods of time according to size of holding. There is consequently much to be said for limiting the capacity of this channel to the delivery stream only, one holding at a time taking the whole stream. The channel as so defined is commonly referred to as a watercourse or field channel. It is usually supplied from a minor canal, the lowest unit of the canal system proper, via an "outlet". The upstream portion of the system, or main stem, may be of higher construction standards than the remainder (e.g. it may be lined) and in some cases it may be operated under Departmental jurisdiction while the branches are operated by the groups of cultivators which they serve (sub-

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1/ Irrigation of crops other than paddy is referred to. In the case of paddy irrigation may be by field-to-field flow of a continuous smaller stream. However rotational irrigation by larger delivery stream is also practicable with paddy, and is in fact desirable during cultivation and puddling.

units of the larger group supplied by the watercourse as a whole). The main stem may be referred to as a watercourse and branches as field channels, or in some localities the whole system is referred to as a field channel. Hydraulically, however, it is a single system, supplied by the outlet and serving each holding in turn.

The Area Supplied by a Watercourse. The Outlet Service Area or Chak. Supply Within the Outlet Service Area

A.3.16 Nomenclature again varies regionally. For present purposes the functional term "outlet service area" is used. Operationally it may or may not be further divided, but for purposes of this discussion it is regarded as the primary supply unit, the first step organizationally above the individual cultivator, the bond between the members of the unit being the common, shared, watercourse. The outlet is the inter-face between the canal system proper (the conveyance system) and the supply unit or user-group. With effective group management of the outlet service area considerable day-to-day flexibility can be exercised in scheduling of deliveries to individual members within the outlet service area. While nominal rotational schedules are usually set up, timing and amount of water supplied to the individual can be adjusted by mutual agreement with his neighbours, taking into account the physical situation of his holding (soil type, drainage condition, etc.) and the nature of his crop. Less flexibility is available in supply to the outlet service area from the canal system proper, which is next discussed.

Supply from the Canal System to Outlets. Operational Limitations, and Options in Design

A.3.17 Up to this point discussion has centred on the downstream portion of the system, the cultivator and the cultivator group within the outlet service area. Attention is now turned to the upstream portion of the system, the conveyance network of main, branch, distributary and minor canals supplying the outlets. Flexibility in operation of the conveyance system and the design and operational implications of various degrees of flexibility are discussed.

A.3.18 Situations which a conveyance system should be capable of accommodating, in some degree, include the following:

a) The normal monthly and seasonal variation in irrigation demand through the year.

b) Deficiencies in the amount of water available to a project in dry years, and consequent unavoidable reductions in deliveries.

c) Differences in cropping pattern and water demand within the project area due to differing soils and topography, etc., either on macro or micro scale.

d) Long-term changes in cropping pattern in the area as a whole, and in pattern of irrigation demand.

e) To the extent possible, random short-term variations in irrigation demand due to rainfall within the service area.

The variations in situations (a) and (b) are unavoidable, although the effectiveness with which they are accommodated depends upon the design and operation of the system. The ability to accommodate differences in cropping pattern <u>within</u> the project is a central issue.

A.3.19 Principal operational features and limitations of canals as currently constructed in the region under discussion, and possible future developments are described below.

<u>Main and Branch (Primary) Canals</u>

i) Discharge is controlled by upstream head-gate, but if adequate level in the canal is to be maintained to ensure rated flow to distributaries the discharge in the main canal often cannot be reduced below one-half rated capacity. There is no provision for maintaining the canal full or near-full at zero flow. Unless it is shut down for a long period the canal must continue in operation.

ii) Features which could be included in future projects, or improvements, range from installation of sufficient cross-regulation to permit level control at much reduced flows, to the ultimate of complete constant-volume control with sufficient cross-regulators to permit level control at all flows, including zero flow, and almost instant response to change in demand (i.e. downstream control). The latter type of installation is likely to be the exception for the foreseeable future, due to high cost. For the present some limitations in rate of discharge in main canals, and in rate of response to changes in demand, must be accepted. However, better communication between control structures is bringing about some improvement in the latter feature. The limited number and large size of control structures on main canals at least ensures constant attendance and freedom from unauthorized operation.

<u>Distributary (Secondary) Canals</u>

i) Distributaries (typically 0.4 to 5 m^3/sec) differ from main or branch canals in two particular respects. Firstly they are smaller and shorter in length so that it becomes possible to operate them intermittently if desired, at least on a fortnightly cycle (shorter periods might not be practical with a large distributary). Secondly there are many more distributaries, with greater aggregate length, and operation and policing of control structures can be a greater problem than with main canals.

ii) The principal question in design of distributaries is how to accommodate conditions at reduced demand. The options are on/off rotation at full nominal capacity, or continuous operation at reduced discharge. 1/ The latter requires installation and operation of cross-regulators on the distributary to permit rated flow to the minor when the distributary is operating at reduced flow, and also operation of gates on each minor if the latter have to be rotated in groups on the distributary under these circumstances.

1/ The merits of rotational operation of distributaries even under conditions of peak demand, as is practiced in some irrigation systems, are not discussed here.

iii) On-off rotation of the distributary during periods of reduced demand is in many respects the simpler solution operationally, but its practicability depends upon the length of the distributary and whether or not it is lined (both factors influence the time required to start and stop flow), also on the relative proportion of time "off", and the desired irrigation interval. If the latter is less than 14 days (which may be required for certain types of crop) on/off rotation of the distributary may not be practical unless it is relatively short.

iv) Each distributary has a head-gate at the parent main or branch canal, and if required can be operated independently of other distributaries, provided that the main canal flow is adjusted accordingly. Each distributary service area can be regarded as a separate individual irrigation system.

Minor (Tertiary) Canals

i) Minors range in capacity from some 0.04 to 0.5 m3/sec. A minor is supplied by a distributary and in turn supplies outlets to watercourses (up to 20 or more). There are a large number of minors on a typical irrigation project and operation and maintenance of minors together with their associated outlets is a subject of considerable concern in irrigation system design. As operation of such small channels at less than design capacity is generally considered to be impractical in view of the problem of maintaining head at a large number of outlets under reduced-flow, regulation of delivery from minors is most frequently by on/off rotation of full-flow. Outlets to watercourses operate together with the parent minor, as a group.

ii) A technical possibility often discussed is the introduction of "downstream control" in minor canals. The minor is divided into a number of level reaches, or is designed as one long "level-top" reach. The water-level in each reach is maintained full by a float controlled gate at its upstream end, the most upstream such gate being at the point of supply from the distributary. Outlets to watercourses are then free to take water, or not to, when desired, the inflow from the distributary automatically adjusting to the demand on the minor. Hydraulically this is similar to the use of a terminal pond, which the distributary maintains full, and from which the minors (or watercourses directly) draw water as required.

A.3.20 Downstream control is virtually a demand system, draw-off being automatically made up by releases from the next upstream reach or canal. As discussed earlier, however, under the circumstances of most Asian smallholder irrigation systems water is allocated, in effect rationed, to the cultivator or cultivator group, supply to the minor from the distributary being scheduled on/off in times of less than peak requirements or restricted supply, to control the amount of water used. In this situation the minor could still be operated on downstream control but on "limited demand", in the sense that supply from the minor is restricted to the periods of scheduled supply from the distributary. It is of course also restricted to the design capacity of the minor. This latter restriction is not of particular consequence as the capacity of the minor is normally equal to the sum of the capacities of the outlets served by it, and demand on the minor consequently cannot exceed its capacity.

A.3.21 The advantage of level control in such circumstances is the saving of water when all outlets are not in operation, for instance when outlet gates are closed by cultivators, possibly due to rain in the service area, or due to lack of perceived need of irrigation or for other reasons. Without level control a minor will spill (via a tail-end structure) in that situation, unless shut down manually. With level control (downstream control) the flow into the minor will be automatically adjusted to the reduced draw-off from the minor.

A.3.22 This, of course, moves the problem into the distributary which will also spill because of reduced draw-off from the minor (or minors) unless the distributary head-gated is manually adjusted, or unless the distributary itself is designed for downstream control. That would again move the regulation problem upstream, into the branch or main canal. However, with adequate controls on the main canal, and possibly with a limited amount of within-canal operational ponds, and considering the likely diversity in demand from the many distributaries on the main canal, the regulation problem could probably be accommodated. In the ultimate case downstream control or constant-volume control can be extended further, up the whole length of the main canal to the reservoir.

A.3.23 Generally pondage in one form or another is required at the interface between downstream control and upstream control, and a decision as to whether to limit downstream control to the minor system or also to include the distributary system can be influenced by availability of pond sites.

A.3.24 Stopping short of the "high technology" of downstream control, the simplest arrangement fitting the circumstances is for the minor to run always at nominal full capacity when operating, supply being scheduled on/off as required, and all outlets operating in concert with the minor. Cross-regulating structures on the minor are not then required (other than possibly fixed bottom-regulators), nor operation of gates at outlets.

A.3.25 To summarize the above discussion:

- With present technology the main and branch canals must run continuously unless shut down for several weeks. However they can be run at reduced discharge (down to half design capacity) and still command full flow to the individual distributaries.

- Distributaries can be operated independently of each other, with corresponding adjustment in main canal. During periods of reduced demand distributaries can be operated on/off (the simplest solution), or may be designed to run at reduced discharge.

- Minors operate only at full flow. They operate in concert with their distributary if it operates at full-flow on/off. On the other hand if the distributary operates continuously at reduced discharge in seasons of low demand the minors rotate in groups on the distributary.

- Outlets to watercourses operate only at full flow, together with their minor.

Required Rate of Supply. Canal Capacity. Accommodation of Varying Supply Within the Project Area

A.3.26 In the previous chapter the supply of irrigation from the main canal down to the outlets from the minor has been discussed in principle. Determination of actual unit canal capacity (per hectare of service area) and operational means of supplying at various rates within the service area are now considered.

A.3.27 In Annex A1 the size of area which can be served, given the annual (or seasonal) amount of water available to a project and the cropping pattern (crop percentage or "crop mix"), is derived arbitrarily, assuming 100% irrigation intensity in the peak season. The corresponding rate of delivery to the area required in the peak month is also determined.

A.3.28 If for social or other reasons the actual service area is made greater than that determined on the basis of peak season irrigation intensity of 100%, then the peak season intensity is reduced accordingly. It is noted in Annex A1 that the required total rate of delivery to the area is unchanged by increasing the service area. The total rate is determined only by the amount of water avalable and the "crop mix". However, the required rate of delivery per unit of service area is reduced in proportion to the increase in total service area. This unit rate of delivery is referred to as the "irrigation duty", usually in litres/sec/ha (or in acres per cfs), assuming continuous supply. If the supply canal does, in fact, operate continuously in the peak season, the capacity per unit of service area (the "canal duty") is the same as the "irrigation duty". If the canal operates for only half the time (e.g 50% on/50% off) the canal duty must be twice the irrigation duty to achieve the required delivery.

A.3.29 With the above summary of Annex A1 as background, more specific questions of irrigation supply can be discussed. Two particular items to consider are firstly what provision should be made for possible future changes in the project-wide cropping pattern, and secondly what degree of diversity in cropping pattern or unit water requirements between one local area and another can be accommodated. Diversity in cropping pattern may mean differences in water requirements per unit area, or differences in the seasonal timing of water requirements. Other variations from the nominal design situation which a project may be faced with are greater or lesser availability of water than estimated in the original hydrological studies, and certainly the occurrence of some years of very much reduced availability.

A.3.30 The most significant effect of a change in cropping pattern is a possible further peaking in water demand. Any project-wide change in pattern is necessarily limited as far as total seasonal demand is concerned by the amount of water available to the project. However the proportion of the annual or seasonal supply required in the peak month may increase, thereby increasing the conveyance capacity needed. For canals which are in any case operating continuously in the peak season this implies increased capacity. For any canals which rotate "on/off" in the peak season increased conveyance capacity can be achieved by increasing the proportion of time the canal is "on". The project-wide nominal irrigation duty (which in most cases is synonymous with main canal capacity per hectare served) should consequently have reasonable margin either on a percentage basis or, preferably, arrived at by consideration of possible specific changes in cropping pattern. Supply at less than the design maximum rate can always be accomplished by rotation on/off of distributaries (subject to limitations discussed earlier), and of minors. The main or branch canal is usually designed to maintain sufficient level at offtakes to distributaries so that individual distributaries can operate (in rotation) at design capacity, with the discharge in the main or branch canal reduced to one-half of the design figure. As rotation of large main canals on/off at weekly or fortnightly intervals is neither desirable nor practical such a limitation in minimum main canal flow below which individual distributaries cannot be operated at full capacity effectively limits the minimum rate of delivery through the system. This can be an undesirable limitation, which should be avoided if possible by provision of sufficient cross-regulators on the main canal to permit maintaining full command head on distributaries with considerably lesser proportion of design delivery in the main canal.

A.3.31 A local variation in cropping pattern on the scale of the entire service area of a distributary can readily be accommodated, as a distributary operates virtually as an independent unit, if sufficient capacity has been provided in the first place either intentionally, to take care of a particular soils situation, or simply as a design margin. Obviously any such diversity in amount of water supplied per hectare implies a method of allocation based on sanctioning of particular requirements, with charges scaled accordingly, rather than on a flat rate pro-rata to area of holding.

A.3.32 A local variation in cropping pattern on the scale of a minor canal and its service area can be accommodated at the time of initial construction, by providing appropriate unit capacity in the minor and by sizing the outlet service areas to suit. However, a minor canal does not normally operate as an independent unit. For simplicity of operation all minors should run together with the parent distributary (or in groups on the distributary). Hence, although it is possible to provide greater or lesser unit capacity on a particular minor, it would be much less convenient operationally, although not impossible, to have one minor requiring its peak supply in a different month from its neighbour on the same distributary, for instance for irrigation of spring paddy in a local low-lying area, while the remainder of the minors are irrigating an upland crop such as wheat. Should such a situation be unavoidable additional control structures would probably be necessary on the distributary, and appropriate operational staff.

A.3.33 A variation in cropping pattern within the service area of the minor itself is in the same category. It is possible to provide a higher unit rate of supply (irrigation duty) to a particular outlet service area, but much more difficult to provide service to an outlet at a different time than the service to adjacent outlets. The minor canal service area should be regarded as the minimum unit for differentiation of cropping pattern and irrigation supply, other than differences which can be accommodated within the outlet service area by mutual arrangement between cultivators supplied by a particular outlet.

A.4 CANAL LINING. DRAINAGE. LAND DEVELOPMENT FOR IRRIGATION

The Case for Lining of Canals

A.4.1 Whether to line canals, and the extent of lining justified, are two much discussed issues in planning of irrigation projects. Most of the major systems constructed earlier in the development of irrigation in South Asia were unlined, and many continue to operate in that condition.

Lining is obviously not mandatory. However, with available water resources approaching full development, and with irrigated agriculture now becoming a key factor in meeting the needs of increasing population, the question of lining of principal canals (main, distributary and minor canals) warrants full consideration in the design of any new project.

A.4.2 There are a number of possible reasons for lining, although not all are relevant to any particular project. They include:

a) Reduction in loss of water by seepage.

b) Inhibiting rise in water-table due to seepage, with possible waterlogging and eventual salinization.

c) Prevention of erosion in critical reaches of a canal.

d) Security against breaching in embankment, particularly due to burrowing animals.

e) For smaller canals (minors) better security of supply to "tailend" areas.

f) Facilitating closer regulation of canal flows than is possible with an unlined canal.

g) Reduction of maintenance, particularly removal of aquatic plants.

h) Reduction of width of right-of-way required in areas of high land value.

i) For health reasons, particularly reduction of incidence of bilharzia (schistosomiasis) in areas where this is endemic.

A.4.3 The argument against lining is of course its capital cost, and if the quality of lining is unsatisfactory its short effective life and the difficulty of maintenance and repairs with a deteriorated lining.

A.4.4 A problem in the economic analysis of a proposal for lining is that benefits from most of the items listed are difficult to evaluate. Seepage loss from an unlined section can be estimated (approximately). This may be a net loss (for instance if it joins ground-water of unusable quality) but it may recharge an aquifer which is already well developed, and could then be re-used.

A.4.5 If canal seepage is <u>not</u> re-used it can directly contribute to waterlogging and eventual salinization. In some situations, even where groundwater quality is good, potential waterlogging can be the primary reason for canal lining. Again, such considerations are difficult to quantify in economic terms.

A.4.6 In the case of minor canals, which collectively account for a major part of total canal seepage, the better security of supply to "tail-end" areas is a primary reason for lining. The benefits can be a dramatic upgrading of irrigated agriculture in those areas.

A.4.7 Facilitation of closer regulation of canal flows, with lined channels, refers back to the earlier discussion of flexibility in operation of distributary and minor canals. A lined channel, being of smaller cross-section, fills more rapidly than an unlined channel, and is capable of on/off rotation on a shorter time cycle. Furthermore flow regulation by hydraulic structures is facilitated with the fixed shape of a lined channel.

A.4.8 Summarizing, analysis of the merits of lining of principal canals is a key issue in project design. However, most of the factors involved are not capable of close economic evaluation. Technical judgement must also be relied upon. The case for lining of main canals, of distributaries, and of minor canals should be examined separately, as lining of one, or two, categories of canal may be warranted where lining of all three may not. Lining in future stages of development of a project may also be considered, where this is technically feasible.

Durability of Canal Linings

A.4.9 A primary issue in evaluation of canal lining is its durability. While linings in many major systems have performed satisfactorily for decades others have deteriorated to a serious degree within three or four years of being placed in service. Repair of a deteriorated lining is difficult, and usually amounts to little more than patching of worst areas, becoming a substantial annual maintenance item.

A.4.10 The problems with linings of principal canals include the following:

a) Formed-in-Place Concrete Linings (Main Canals)

i) Deterioration of joints, and establishment of weed growth in joints.

ii) Erosion of material from behind lining through deteriorated joints.

iii) Cracking in embankment section due to settlement of fill, the crack usually running horizontally about half way up the sloping side of the lining.

iv) Very poor quality concrete with low proportion of cement, surfaced with cement plaster. Inadequate curing. On cracking due to shrinkage or settlement the plaster flakes off and the exposed low-cement concrete deteriorates rapidly.

v) Cracking due to major movement of expansive clay soils.

vi) Displacement due to hydrostatic pressure behind lining on draw-down of water level in canal.

b) Brick Lining (Conventional Brick, and Brick Tile)

- The same problems as listed above, except items (i) and (iv). Penetration of cracks by weed growth is a frequent cause of progressive deterioration in brick linings.

c) Stone-Slab Lining

- A particular problem is failure of joints. Hair-cracking due to shrinkage is followed by seepage, also displacement of slabs, and further leakage and erosion of material behind the lining, in some cases aggravated by activity of crabs and rodents. Theft of slabs can also be a problem. A double layer of slabs with staggered joints and mortar between the layers has proved more durable, but at considerably higher cost.

d) Pre-Cast Concrete Slabs

- The problem again is the joints, and heavy weed growth in hair cracks at joints is frequently observed. However, precasting offers the possibility of shaped overlapping joints, better capable of resisting displacement and providing better seal than simple rectangular joints.

A.4.11 Remedies for some of the above deficiencies are obvious, including better compaction of canal embankments against which linings are placed, better quality control of cast-in-place linings and the use of plastic joint seals in such linings, and improved joint design in precast slab linings. The use of plastic sheet (polyethylene or PVC) behind brick or slab linings as the primary retaining element is also of increasing importance. Plastic sheet linings with earth-cover (buried membrane linings) or earth on the canal bottom and concrete slabs on the side, are also being used, particularly for larger canals where animal-access is not a problem, nor bottom rooting aquatic plants.

Lining of Watercourses

A.4.12 This is a separate subject, due to the possible use of integral (full-section) pre-cast units in the case of such small channels. Watercourse linings are discussed in Annex B1. The questions of whether or not watercourses should be lined, and what proportion of a watercourse should be lined, are much debated, also whether the cultivators served by a watercourse should contribute part or all of the cost of lining. Technically lining is particularly indicated where seepage losses in unlined channels would be high, and where erosion in down-slope channels would be a problem. Where part only of a branching watercourse system is to be lined there is a case for giving priority to lining the main stem, as it is in service for a greater proportion of time than the outer branches. Limitation of the maximum length of run of unlined channel may also be a criterion in determining the extent of lining. As noted in regard to lining of principal canals, the benefits from lining of watercourses are usually real enough, but they are not easy to evaluate closely in economic terms. The question of lining is more likely to be decided on grounds of qualitative judgement and financial constraints, than on strictly economic arguments.

Drainage Problems in Irrigation. Surface and Sub-Surface Drainage

A.4.13 Aggravation of drainage problems can be one of the negative contributions of irrigation. It is not uncommon to find local areas which were previously under satisfactory rain-fed cultivation, but which with the advent of an irrigation project in their vicinity have become waterlogged to the extent of now being completely out of production. Anticipation and avoidance of such situations is an essential feature of the design of an irrigation project.

A.4.14 Drainage may be required for the following purposes:

i) Conveyance of irrigation spill from minor canals, watercourses, and in some cases from irrigated fields.

ii) Removal of rain-water from cropped fields (agricultural drainage).

iii) Conveyance of storm runoff at crossings of canals, roads, etc. (structural drainage).

iv) Sub-surface drainage (abstraction of groundwater for control of water-table.)

A.4.15 While the merits of an adequate drainage system are self-evident, maintenance of drainage channels is a perennial problem in South Asia smallholder irrigation areas, due to infestation with phreatophyte plants and for other reasons including obstruction by cultivators. Design of drainage works should consequently be selective, with emphasis on maximum use of natural topographic drainage features, and with construction of new drainage channels limited as far as possible to essential improvement of primary and secondary drainage, and such additional drainage as there is prospect of maintaining in operating condition. Obviously interpretation of the latter reservation will depend upon the degree of discipline and the level of maintenance within the individual project.

A.4.16 In the following brief notes emphasis is placed on problems, to the exclusion of drainage hydrology and design criteria.

A.4.17 With regard to cross-drainage structures under canals where failure can be of serious consequence, a frequent source of trouble can be blocking of culverts with debris and silt during heavy runoff. The use of a short section of aqueduct has much to recommend it at drainage crossings under small lined canals, due to the generous water-way which can easily be provided at modest cost.

A.4.18 The extent of provision for agricultural drainage leaves more room for choice than in the case of structural drainage. The consequences of inundation of a crop for thirty-six hours rather than for twenty-four are probably marginal. The main source of ponding of storm-water on fields is usually backing-up of water from obstructed or inadequate primary drainage, rather than the lack of collector or field drains, and primary drainage should be the priority item both in construction and in maintenance of drainage works.

A.4.19 Common maintenance problems include the following:

- Infestation with plants such as bull-rushes (Typha) and Ipomoea. Both of these are very difficult to control without frequent cutting; control of the Ipomoea is so far almost impossible. Drains which dry out in the summer present less of a problem with Typha, but Ipomoea thrives also in dry conditions. In wet-tropic areas water hyacinth is a major problem in large drainage channels.

- Difficulty in maintaining cross-section at depth in channels in erodible soils, particularly certain clays, or in "quick" conditions in silty soils.

- Blocking of drains by cultivators, either to convert them into supplemental irrigation channels or ponds, or for fish culture, or simply for access across drains. While it would appear that this could be resolved by use of authority in the area, in fact it is a major problem in some localities.

A.4.20 The most serious drainage problem being encountered in some irrigation areas is a rise in water-table and wide-spread waterlogging, followed by salinization and in some cases development of alkalinity. Such a condition can arise, almost inevitably in some situations, in very flat topography with near-flat sub-surface drainage gradient. Under rainfed conditions a balance exists between transpiration and precipitation, with very little lateral movement of groundwater. With the addition of irrigation, vegetative growth and transpiration increase to some extent, but there is a net downward flow to the water-table unless irrigation and consumptive use are very finely balanced. Seepage from irrigation canals adds to this amount. The water-table rises in consequence until a new balance is arrived at, between increased lateral movement of groundwater due to the increased gradient, and surface runoff or greater transpiration where the water-table approaches the surface (i.e. when waterlogging occurs). The increased lateral movement is very small in the topographic situation described, and the advent of waterlogging may be simply a matter of time - historic time in some cases and three or four years only in others.

A.4.21 Possible remedies include the following:

- Restriction in the amount of irrigation applied.

- Lining of canals and watercourses to minimize seepage.

- Encouragement of consumptive use of groundwater by private wells, if it is of usable quality.

- Consumptive use of groundwater by public wells, either direct irrigation or conjunctive use with canal supply, again only if of usable quality.

- Groundwater drainage by relatively deep open channels, if lateral permeability is sufficient to permit an acceptable spacing of such channels (which is not generally the case).

- Tile-drainage (or tube-drainage) and consumptive use of drainage effluent.

A.4.22 While tube drainage is regarded as a relative high-cost solution in South Asia, its use may be the only alternative to abandonment in some cases.

A.4.23 In heavy clay soils there may be a high water-table even when there are sub-surface drainage gradients of 1% or more, due to the very low lateral permeability of such soils. An interesting variation on the heavy clay soil situation occurs in the Deccan trap (basaltic) area of central India, where the clay soil (a vertisol) is generally underlain at 2 to 3 m depth by a relatively pervious granular horizon ("murrum") immediately overlying the parent rock. This can facilitate tube-drainage of the overlying clay soils, a possibility which is currently being investigated in that area.

A.4.24 To conclude, sub-surface drainage conditions and possible adverse developments under irrigation, on local or larger scale, should be looked into in all irrigation projects. The customary 2 m soil profiles taken during soil surveying are not deep enough for sub-surface drainage investigations, unless bedrock occurs within that depth.

DERIVATION OF CANAL CAPACITY. IRRIGATION DUTY AND CANAL DUTY. DETERMINATION OF SIZE OF OUTLET SERVICE AREA

1. In converting figures for consumptive use and irrigation requirements (in millimetres per day or per fortnight) into rate of supply from the canal system it is convenient to take a nominal 100 ha of the service area and to assume for the moment that it is fully occupied by crops (100% seasonal irrigation intensity) in the peak season. By reference to the design cropping pattern a bar chart is then drawn up showing the hectares of each crop on the ground month by month throughout the year. Using the figures for irrigation requirement for each crop, and converting from millimetres/day to cubic metres per fortnight for the respective area of each crop, a total figure for cubic metres of water required in each fortnight of the year is obtained. This is for the nominal 100 ha of service area assumed for the moment to be under 100% irrigation intensity in the peak season. The fortnightly totals may be converted into seasonal and annual quantities of water, also into rate of supply in cubic metres per month in the peak month, or into cubic metres per second in that month, or into litres per second per hectare of the nominal area in the peak month. It is again noted that the nominal 100 ha area is assumed to have 100% irrigation intensity in the peak season. Actual irrigation intensities may be less. Nevertheless the nominal area is a useful tool. By comparing the seasonal quantities of water required for the nominal 100 ha area with the amount available, the total area in hectares which could be served with 100% irrigation intensity in the peak season is obtained. Assume for example that this is 10,000 ha. The equivalent rate of supply required from the canal is the figure for cubic metres/month in the peak month for 100 ha multiplied by 100. 1/

2. Turning now to the actual area to be served by the project, it may be desired on socio-economic grounds to provide reduced irrigation over a larger area rather than full irrigation to a smaller. In the above case, for instance to 15,000 ha rather than 10,000 ha. The availability of water remains unchanged by this increase, and also the delivery of water to the area in cubic metres/month in the peak month, and hence also the canal capacity is unchanged. However the following items are changed:

a) The irrigation intensity is reduced from 100% to 10,000/15,000 x 100 or 66%.

b) The amount of water applied seasonally or annually per hectare of service area (either in cubic metres per hectare or simply in millimetres depth) is reduced by 33%.

c) The peak rate of supply in litres per second per hectare of service area is also reduced by 33%.

1/ For simplicity in this discussion no distinction is made between rate of supply at the field and in the canal, i.e. delivery efficiency is assumed for the moment to be 100%. Actual rates of supply would have to be increased to compensate for delivery system losses.

3. As noted in earlier discussions, the depth of water applied annually, calculated over the service area as a whole, is a function solely of the amount of water available and the size of service area. It is independent of cropping pattern or irrigation intensity, and is an excellent index of water use. Canal capacity, in cubic metres/second, is related to availability of water and hence is independent of size of service area. It is, however, influenced by cropping pattern which determines the proportion of the annual supply which is delivered in each particular month.

4. The peak rate of supply in litres per second per hectare of service area (the "irrigation duty") is a very useful figure in irrigation system design, but requires some qualification when applied at the farm level. Applied to a main canal which is running continuously, it is simply the amount delivered per month (in the peak month) converted from cubic metres/month/hectare to litres/second/hectare. However, if used to obtain the capacity of a canal which is designed to run only 50% of the time in the peak season (common in some small Tank schemes) rather than continuously, the capacity of the canal would have to be doubled (in the above case to 2.0 litres/sec/ha) to give the same monthly delivery. Hence distinction should be made between an "irrigation duty" of 1.0 litre/sec/ha (continuous) and a "canal duty" of 2.0 litres/sec/ha.

5. If the minor and its outlets are to operate <u>continuously</u> in the peak season and the water duty (continuous) is for instance 1.0 litre/sec/ha, then the watercourse duty would also be 1.0 litre/sec/ha (adjusted for losses en route). If the desired delivery stream (and outlet capacity) is for instance between 15 litres/sec and 25 litres/sec, the area of the outlet service area must lie correspondingly between 15 and 25 ha, the actual capacity of the outlet matching the actual size of the service area as dictated by topographic and other factors. The supply to the individual holding is of course not continuous. With a water duty of 1.0 litre/sec/ha (continuously) and a delivery stream of say 20 litres/sec, a holding of, for example, 2 ha would receive water for 2/20 or one-tenth of the time (about 17 hours per week or 34 hours per fortnight).

6. If on the other hand the minor and its outlets were to operate <u>discontinuously</u> in the peak season (for instance 50% on/50% off as in day-time-only irrigation with very small tanks) the watercourse duty in the above case would be doubled to 2.0 litres/sec/ha to achieve the same monthly delivery per hectare. With the desired delivery stream unchanged at 15/2 and 25/2 or 7.5 and 12.5 litres/sec, the outlet service area would then lie between 7.5 and 12.5 ha. 1/

1/ The question of size of delivery stream and size of outlet command under various conditions are discussed in more detail in Paper C of Volume I.

PAPER B

WATER DISTRIBUTION FROM MINOR CANAL TO THE FIELD, AND LAND SHAPING IN IRRIGATION OF SMALLHOLDINGS

B. WATER DISTRIBUTION FROM MINOR CANAL TO THE FIELD, AND LAND SHAPING IN IRRIGATION OF SMALLHOLDINGS

B.1 INTRODUCTION AND DEFINITIONS

B.1.1 In the operation of an irrigation system serving small free-holdings the administrative boundary between the canal system and the distribution system supplying the farm is at the outlet from the minor canal. Upstream of this point management of the system is by the Irrigation Department; downstream of the outlet the cultivators are closely involved in the management of water distribution. Much of the attention of agencies involved in irrigation is directed at the development of this downstream part of the system, which has generally proved to be the controlling factor in bringing new irrigation projects into effective production. The problems encountered are in part technical, but to a greater extent relate to the degree to which the cultivators supplied by an outlet are willing to undertake group responsibility for day-to-day operation and maintenance of the distribution system.

B.1.2 In the following paper the design and construction of distribution systems below the outlet from the minor canal are considered, also on-farm development for irrigation (land shaping), and the role of cultivators in management of water distribution. As nomenclature adopted in the description of irrigation systems varies regionally it is desirable to define the terms employed. In the following discussions the area served by an outlet from a minor canal (commonly in the range of 15 to 40 ha) is referred to as an "outlet command". The channel distributing water within the outlet command is referred to as a "watercourse" which may branch into "field channels" (discussed later). Individual farms are supplied by turnouts. Distribution within the farm is by "farm channel". The total area covered by the canal system, and capable of being irrigated subject to availability of water, is referred to as the service area or net command area (see Plate 1).

B.2 SUPPLY TO THE MINOR CANAL OUTLET

The Irrigation System as a Whole. Determination of Capacity of Main Canal and Size of Service Area

B.2.1 Problems encountered in management of water distribution within the outlet command are frequently due to limitations or deficiencies in the supply of water to the outlet, from the main canal system. Such deficiencies may be technical, and possibly avoidable, or they may be inherent in the variable nature of the yield from the project catchment. It must be recognized that an irrigation project simply takes river-flows, partially regulates them to the extent that storage is available, and conveys them to the area to be irrigated. The project has to accommodate the varying seasonal and annual availability of water. Storage can assist in reducing the effect of annual variation in inflow, but usually only partially. Where cultivators are served by a small Tank scheme adjacent to their village the amount of water available in storage in a particular season is visible for all to see, and the need for restriction in irrigation supply should this be necessary is readily apparent. It is less evident, however, in the case of cultivators who are served by a major canal which originates in some distant source, and which continues downstream to supply other areas. In the latter situation the cultivators in question may feel that any restriction in supply to their particular area is due to upstream mismanagement, and that they are justified in meeting their needs by unauthorized manipulation of regulating structures or by whatever other means are available to them, without regard to downstream users.

B.2.2 Many of the problems of irrigation management at the level of the outlet command are in fact due to conflict between the desires of cultivators and the realities of the supply position. Others, however, stem from operational constraints within the canal system, not directly related to availability of water. The design of the irrigation system as a whole, from reservoir down to the outlet from the minor, and the constraints on supply to the outlet, are discussed in detail in the companion paper, "Issues and Options in Design of Reservoir and Canal Systems".

B.2.3 The latter paper should be referred to for further background. However, for convenience the principal factors on system design which influence the supply of water to the outlet from the minor are summarized hereunder.

B.2.4 The basic steps in design of an irrigation system as a whole are the following:

a) Estimation of probable seasonal and annual inflow available to the project.

b) Determination of the amount of storage capacity which is to be provided.

c) Consideration of how this storage may be used (i.e to provide supplemental irrigation in the wet season, or full irrigation in the dry).

d) Exploration of a range of likely future cropping patterns, and in each case determination, by trial, of the canal capacity which would be required to serve such a cropping pattern, within the limits of seasonal and annual availability of water. This step matches cropping pattern (or "crop mix") with available water and canal capacity. It also provides a figure for the size of service area required to utilize the water available in each case, assuming 100% of the service area is under irrigation in the peak season.

e) Decision whether, in fact, 100% of the service area is to be under irrigation in the peak season, or whether for social or other reasons the available water is to be spread over a larger area. In the latter case sufficient water is supplied for irrigation of part only of each holding, but a larger number of holdings are covered (i.e larger service area).

f) Decision as to whether irrigation should be supplied at the same rate per unit of service area throughout the service area, or whether some portions of the area should be provided with more water (higher water duty) than others.

B.2.5 From the above procedure the following are determined:

- Reservoir capacity
- Main canal capacity at reservoir outlet
- Size of service area (net command area)

B.2.6 Although a number of alternative cropping patterns, usually including a nominal "project" pattern, may be considered in the process of arriving at a canal capacity, future operation of the project is not committed to any such pattern. Changes in cropping pattern can be accommodated at any time provided that the maximum rate of water delivery required is within the canal capacity as constructed, and that seasonal and annual water requirements are not greater than the available amount. The irrigation intensity arrived at in the process of balancing cropping pattern, crop water requirements, availability of water, and adopted size of service area, is also a nominal figure. It is not an inherent feature of the project. Higher water-use crops can be accommodated simply by reducing the area of irrigated crop (the irrigation intensity) to compensate for the higher water use. This applies equally to the project as a whole and to the individual cultivator.

The Main Canal. Rate of Delivery per Unit of Service Area. Operation at Reduced Discharge. Response to Demand

B.2.7 Derivation of the capacity of the main canal from the amount of water available to the project, and the seasonal distribution of water requirements, is discussed above. The "design" or maximum capacity is usually expressed as the rate of delivery per unit of area of net project command, averaged over the command, and calculated at the upstream end of the main canal. This is commonly referred to as the "canal duty" (in litres/second/hectare of command, or acres per cfs).

B.2.8 In most cases water is supplied from the main canal at the same rate per hectare throughout the command. However, where the command is divided into areas of substantially different soil types with different cropping potential the rate may vary in different reaches of the canal. In the simplest case, with uniform rate throughout and all canals (distributary, minor, and watercourse) operating continuously in the season of peak delivery, the canal duty at the outlet from the minor is the same as at the head of the main canal, with adjustment for losses en route. For instance if the duty at the main canal head is 1.0 litre/sec/ha of command and conveyance losses down to minor outlets average 10% (a lined system), the duty at the outlets becomes 0.9 litres/sec/ha, simply equating rates of inflow and outflow to the canal system. However, in certain situations discussed later the duty at the outlet from the minor may differ considerably from that at main canal head.

B.2.9 The upper limit to rate of discharge in the main canal, short of encroachment on freeboard, is the design capacity discussed above. With most canals there is also a lower practical limit to the rate of discharge, dictated by the minimum depth required in the main canal at off-takes to distributaries if full-flow is to be maintained in the latter. 1/ A common

1/ In this paper main canals are assumed to be lined, as in current practice. The need to maintain "regime flow" to avoid erosion or silting, a factor in the operation of earlier unlined major canals, is not considered herein.

practice is to design the off-take to distributaries such that full design flow is achievable in the distributaries while flow in the main canal is down to half design capacity, or alternatively at half normal maximum depth (corresponding to some 30% of design capacity).

B.2.10 To permit operation of the main canal at lesser flows, while still providing for full design discharge at a proportion of distributaries, it is necessary to provide control structures (cross-regulators) in the main canal at off-takes to distributaries, or at other suitable locations. This is carried to the ultimate extent in "constant-volume" canal design, in which the level in the main canal varies by a small amount only, while canal discharge varies from maximum down to nil.

B.2.11 Where a full complement of cross-regulators is not provided, however, there is a lower limit of some 30% to 50% of design capacity below which the main canal cannot be operated without substantially reducing the rate of flow to individual distributaries. If it is essential that supply from the main canal be reduced still further in such circumstances the main canal must be rotated on/off. However, with a major canal the emptying and refilling times are relatively long and the cycle time, which determines the minimum irrigation interval at the outlet from the minor, may be two to four weeks, depending upon the length of the canal.

B.2.12 In discussion so far the relationship between water duty in the main canal and at the minor outlet has been considered, and also limitations which canal operation at very reduced deliveries (involving canal rotation) may impose on frequency of irrigation within the outlet command. There is one further respect in which the hydraulics of the main canal system impose restrictions on operation within the outlet command. This is with regard to rate of change of supply to the outlet, i.e. response to changing demand. The considerable momentum of the flowing water in a long canal precludes any rapid change in rate of supply unless sophisticated "down-stream control" or "constant-volume" systems are employed. In the absence of such systems, or the use of lateral or terminal ponds which accommodate short-term differences between canal supply and water use at the field, the canal system cannot respond immediately to rapid changes in demand at the minor outlets. Supply must be scheduled in advance, and the skill with which changing demand is anticipated, and reflected in scheduling, largely determines the operational efficiency of a canal system.

The Distributary Canal. Capacity. Rotational Operation

B.2.13 As noted earlier, in the simple case of uniform rate of supply throughout a project command the canal duty is the same (subject to allowance for conveyance losses) for the minor outlet as for the main canal, and the same comment applies to the distributary canals. However, where there is a case for differentiating between the rate of supply to one area in comparison with the remainder of the command, on grounds of soil type or drainage conditions or for other reasons, the design capacity of the individual distributary may have to be separately calculated, and also the capacities of the associated minor canals. Nominally, the total capacity of all distributaries should equal the capacity of the main canal, less conveyance losses. However, a frequent practice is to provide additional capacity (some 10-15% above the calculated figure) in each distributary, and also in minors. It would obviously not be possible to run all distributaries at 10% more than the calculated nominal rate, as the total would be 10% greater than main canal capacity. This provision of additional capacity is to accommodate later adjustment in the duty, or in the area of command, of individual distributaries. Such adjustments (upward or downwards) have to be in balance in total, as the sum of the diversions to distributaries must match the main canal capacity.

B.2.14 Releases to distributaries are controlled Departmentally, rather than being on demand, and irrigation is in progress in all outlet commands simultaneously. (Rotation in the peak season is <u>within</u> the outlet command. Hence there is little diversity in rate of water use from one minor or distributary to another.)

B.2.15 The above discussion applies to smallholder irrigation. A very different situation may be encountered with estate farming, with water supply on demand, or limited demand. The units being irrigated are much larger, and irrigation may be concentrated at any particular time in one local area. In such circumstances a diversity factor of 50% or more in canal duty, over and above system average, may be applied to distributaries, and up to 100% on minors.

B.2.16 Returning to smallholder irrigation, if minor canals (in some cases distributaries) are designed to be operated rotationally (50% on/50% off) <u>even in the season of peak demand</u>, the duty in such canals and their outlets must be 100% greater than in the more usual case of constant supply in the peak season.

B.2.17 To recapitulate:

- The duty, or rate of supply per hectare, is commonly uniform throughout a project command, but may vary from one distributary to another.

- The nominal capacities of all distributaries should, in total, equate to the main canal capacity less transit losses (all distributaries are taken as operating continuously, with the main canal, in the season of peak demand).

- The actual capacity provided in each distributary may be up to 10% greater than the nominal figure, to permit subsequent adjustment (upwards or downwards) in rate of supply to individual distributary commands.

B.2.18 Supply in periods of less than peak demand may be handled either by rotational operation of individual distributaries, or by continuous operation at reduced flow. The former is generally preferred, with all minors and all minor outlets operating in concert with the distributary. Operation at reduced flow is technically feasible but involves more hydraulic controls than full-flow rotation. Due to the shorter length of distributary canals, compared with main canals, the period of rotation and the associated irrigation interval are also relatively short and are unlikely to present a problem at the farm level, in the case of rotational operation of distributaries.

The Minor Canal

B.2.19 Much of what has been said above with regard to distributaries applies equally to minor canals. Minors may operate rotationally on distributaries in the peak season, in which case the design duty (rate of supply per hectare) of the minor and the minor outlets is twice that of the distributary. More commonly, however, the minors operate continuously with the distributary, and have the same design duty (adjusted for conveyance losses), unless there is a case for a higher duty for a particular minor command.

B.2.20 Minors may also be provided with additional capacity over and above the nominal figure, at least as much as that of the parent distributary, and possibly up to 20% of nominal, particularly where the size of the net command of the individual minors is not closely defined at the time of deciding their capacity.

B.2.21 Distributaries and, in some areas, minors should have an adjustable head-gate and flow-measuring device such that the actual discharge can be set at the finally desired amount, and the gate locked in that position. The accuracy with which the discharge can be so regulated depends upon the geometry of the site (e.g. whether sufficient hydraulic head is available for "critical flow" conditions at the control point), the sophistication of the regulating device, and the likely incidence of unauthorized tampering or vandalism. This subject is not pursued herein except to note that robustness is of greater importance than precision in regulating devices at this downstream end of the canal system, where there is a minimum of supervision and a maximum of exposure to damage.

B.3 DISTRIBUTION BELOW THE OUTLET FROM THE MINOR

Rate of Delivery to the Farm Turnout

B.3.1 An undesirably small rate of supply is a principal cause of low efficiency in traditional smallholder irrigation. With such small flows seepage losses in farm distribution channels are relatively high, and the rate of spread of water in the field or furrow is too slow for uniform application. The situation is usually associated with a braided watercourse system, many cultivators sharing the available water at the same time, and taking it for protracted periods to compensate for the low rate of flow which each receives. Probably the most significant improvement aimed at in new irrigation projects, or in modernization schemes, is the provision of an adequate rate of flow at the farm turnout for efficient farm distribution and field application.

B.3.2 The desirable amount, the "delivery stream", is determined by a number of factors including the size of the farm (length of distribution channel, size of plot), the infiltration rate of the soil, topographic slope, the skill of the cultivator, etc. It is a range rather than a specific value in any particular situation, for instance 10 to 15 litres/sec or 20 to 30 litres/sec. The lower limit, where water is to be distributed by farm channel, is in fact some 10 litres/sec and the upper limit is probably around 45 litres/sec, the latter value being appropriate to a large well-developed farm in near-flat topography and with high infiltration rate soils.

B.3.3 A decision regarding the limits or range of desirable size of delivery stream is a first step in the design of water distribution within a particular outlet command. The significance of this decision on design of the outlet command is discussed later.

Supply to One Turnout at a Time versus to More than One. Rotational Supply to Turnouts

B.3.4 The channel served by the outlet from the minor canal could be designed to supply more than one farm turnout at a time. However, in the practice generally being adopted in India the whole flow is delivered to one turnout only at a time. In that case the flow at the outlet from the minor, and in the watercourse, is equal to the delivery stream (with allowance for seepage losses). This is virtually the definition of a "watercourse" in Indian usage. The merit of this practice is that there is no question of the rate of flow which each cultivator receives in turn; it is the whole flow at the outlet from the minor, less seepage losses in the watercourse. If the channel were to serve two cultivators (or turnouts) simultaneously the problem of equality of division between the two would arise.

B.3.5 Rotational supply to individual turnouts is simple in concept, but it is not always readily accepted by cultivators. However, in view of the considerable number of turnouts on a watercourse Departmental operation would be impractical on a permanent basis, and must eventually be taken over by the cultivators themselves, or by a cultivator appointee.

B.3.6 Departmental supervision may nevertheless be necessary for an interim period. Cultivator organization within the watercourse command is discussed further in paras B.4.15 and B.8.2.

Allocation of Water to Holdings

B.3.7 The method of allocation of water to cultivators is one of the most debated questions in irrigation of smallholdings. Both social and agronomic factors are involved. There are two basic approaches. In one entitlement to water is directly in proportion to size of holding. There is no restriction on type of crop grown, but charges are based on type and area of crop.

B.3.8 In the other, each cultivator makes application for irrigation of a particular area of a particular crop (or areas of several crops) in advance of each season. The area of crop actually authorized (sanctioned) to each cultivator in that season, and in effect his entitlement to water, is determined by the Irrigation Department with due regard to the total of the applications received and the anticipated availability of water. Water charges are again based upon type and area of crop sanctioned.

B.3.9 In neither of the above cases is water charged for on a direct volumetric basis. Volumetric charging is not practised in smallholder irrigation in the Asian area for several reasons. Firstly in most projects water is in short supply in the dry season, and is allocated rather than being made available in response to individual demand. Furthermore, as the rates charged for irrigation supply rarely cover the full cost of production of water, particularly recovery of capital cost, water is in effect subsidized, again an argument for equitable allocation rather than supply on demand. Thirdly the problem of vandalism of water meters has usually defeated any attempts at introduction of direct metering at the farm.

B.3.10 Volumetric charging for water has, however, proved to be quite practical at the level of the distributary or minor command. The cultivators served by the distributary constitute, in effect, a Water Cooperative, which manages distribution within its area. Water supply to the distributary is on the basis of limited demand, and is metered at the distributary head. What amounts to volumetric charging is also practised with the Uttar Pradesh public tubewell system, where cultivators are charged on the basis of number of hours of tubewell supply used, regardless of type or area of crop grown. 1/

B.3.11 Allocation of water on the basis of area of holding, and the alternative of seasonal sanctioning of type and area of crop to be grown, both have merits in particular circumstances. The first is simple to administer, and where water is in short supply it encourages economy in water use. It is traditionally practised in north-western India. On the other hand seasonal sanctioning of water for particular crops has advantages where soils and types of crop vary considerably within a project command.

B.4 THE WATERCOURSE SYSTEM

Size of Area Served by a Watercourse. The Outlet Command

B.4.1 The two principal factors which determine the upper and lower limits of the range of area of the outlet command are the design rate of delivery from the canal system at the outlet from the minor per unit of service area, and the desirable rate of flow at the farm turnout.

B.4.2 The derivation of the design duty of distributary and minor canals has been discussed earlier. Usually outlets from a minor canal are designed to operate together with the minor, particularly in the season of peak demand, rather than rotating on the minor. This avoids the need for opening and closing of outlets, and is a highly desirable operational feature. The design duty of the outlets (flow per hectare) is hence related to the duty of the parent minor (less seepage losses in the minor if these are appreciable). In most cases the design duties of all outlets on a minor are the same. However, where a minor serves an area which includes widely different soil types and cropping potential (such as a local area of poorly drained wetland limited to paddy in a minor command otherwise suited to diversified non-paddy crops) there may be a case for a higher water duty in a portion of the area, provided that balance is preserved between inflow to the minor and total outflow to all its watercourses.

B.4.3 For purposes of present discussion the minor is assumed to have a design duty of 0.9 litres/sec/ha at the offtake from the distributary, and all outlets served by it have a uniform design duty of 0.85 litres/sec/ha, the difference being seepage losses in the minor. The minor and its outlets are assumed to operate continuously in the season of peak demand.

1/ For further details see Volume II, "Tubewell and River-Lift Irrigation".

B.4.4 The factors influencing the desirable rate of flow at the farm turnout, the "delivery stream", were briefly discussed in paras B.3.1-B.3.3. For a particular situation (soils, topography, etc.) there is a range of flow at the turnout over which reasonable efficiency in farm distribution and field application is attainable. The corresponding rate of flow at the outlet from the minor is nominally equal to the flow at the turnout plus the seepage loss between the two. The amount of the latter will depend upon the extent of lining and the length of watercourse between the outlet and the particular turnout in question, and may be as high as 20% of the flow at the outlet. It is evident that a uniform rate of delivery at all turnouts throughout the length of the watercourse cannot be assured. The rate of delivery will necessarily be greater at the head end of the watercourse than at the tail end. However, this variation can generally be accommodated within the acceptable range of rate of delivery to the turnout. 1/ It is convenient in fact, to make allowances for seepage loss in the watercourse and to derive an adjusted range of rate of delivery at the outlet from the minor. For example 15 to 25 litres/sec at the turnout might be converted to 20 to 30 litres/sec at the outlet.

B.4.5 To summarize, in the case being considered the outlets from the minor have a design water duty of 0.85 litres/sec/ha (continuous operation), and the desirable rate of delivery to the turnout, adjusted to the outlet from the minor, is in the range of 20 to 30 litres/sec. The corresponding areas of outlet command are calculated as follows:

Rate of Delivery to the Outlet	Duty at the Outlet	Corresponding Commandable Area
(litres/sec)	(litres/sec/ha)	
20	0.85	$\frac{20}{0.85} = 23.5$ ha
30	0.85	$\frac{30}{0.85} = 35$ ha

Thus, if the duty of 0.85 litres/sec/ha is to be adhered to, and rates of delivery at the outlet are to be in the range of 20 to 30 litres/sec, the areas of outlet command must be kept within the range of approximately 23 to 35 ha. It is emphasized that the calculation is based on the normal or "design" water duty. If the minor is operated for short periods at higher than normal capacity the rates of delivery at the outlets and turnouts will also be increased.

1/ The difference in actual rate of delivery at turnouts is compensated, as far as equity in total quantity of water is concerned, by giving correspondingly longer rotational turns in the lower end of the watercourse system.

B.4.6 The two factors discussed above define the range of size of outlet command, for a particular minor. Within that range a number of other considerations influence the actual size of each particular outlet command and the location of its boundaries. These include topographic features such as drainage channels, property boundaries, occurrence of local areas of radically different soils or drainage conditions, and location of village boundaries. The latter factor is particularly emphasized as it is very desirable to preserve social homogeneity, as far as possible, within each individual outlet command.

B.4.7 The factors noted may often be in conflict with the aim of keeping within the desirable range of size of outlet command, particularly the lower limit of size. Some variation from the lower limit of rate of delivery (and consequently of size of outlet command) may be acceptable, but not to the extent of generally ignoring the lower limit. Combining neighbouring small areas by carrying a watercourse across an intervening drainage feature, at some structural cost, may be preferable to having two separate outlet commands each of undesirably small size. Where an individual small outlet command is unavoidable and the calculated rate of delivery for continuous supply in the peak season at the design duty would be much too small for efficient water management, the alternative courses are to supply at a larger rate and to rotate the supply to that particular outlet, or to run the outlet continuously at that larger rate, accepting the fact of excessive supply to the outlet in question (a higher than rated duty). The choice would depend upon the anticipated level of operational management of the minor and watercourse system. Where avoidance of the need for opening and closing of outlet gates is most desirable the second alternative might be chosen. Otherwise the inconvenience of gate operation might be accepted in the particular case, the operational disadvantage possibly being mitigated by "pairing" two small-sized outlet commands (rotating from one to the other) to avoid the need for adjustment of flow in the minor each time an individual outlet is rotated on/off.

Layout of the Watercourse and Field Channel System

B.4.8 Once the range in capacity of watercourses and the corresponding size of outlet commands have been established, the task of locating the boundaries of the individual outlet commands and laying out the watercourse/field channel systems can proceed. In some cases this is a relatively simple operation; in others it is much less straightforward. In the simplest case topography is near flat or gently sloping, and holdings are consolidated in a rectangular pattern designed to facilitate water distribution. One of the classic text-book rectangular networks of watercourses, field drains, and access roads may then be adopted. Design of the distribution system may be further facilitated if land shaping is unified within the outlet command and carried out in conjunction with the layout and construction of the watercourse system. This type of situation does occur in Asian irrigation, but it is the exception rather than the rule. For reasons discussed later consolidation of holdings is not everywhere practised, and watercourse systems have to be designed around the existing cadastral situation. Land shaping in that case is usually carried out within the holding, or fraction of a holding, as a unit, and generally after watercourse construction rather than in conjunction with it. The difficulty of watercourse layout is compounded if the topography is irregular and includes areas of relatively steep slopes. Projects with small commands such as "Tank" schemes, with total service area of 50 to 500 ha, may pose additional problems in watercourse layout due to the narrow width of the upper portion of the command.

B.4.9 Because of the diversity of situations which may be encountered in the design of watercourse systems it is difficult to make specific recommendations of general application in layout. In other than the simplest topographic conditions a good deal of judgement is required in each case, a factor which makes watercourse layout and construction a problem in irrigation development and the most frequent cause of delay in bringing projects effectively into service.

B.4.10 For present purposes two situations are described. The first is typical of the command of a large project in gently rolling topography with moderate slopes. Size of holdings (more specifically of parcels, where holdings are fractionated) is in the range of 0.25 to 4 ha. 1/ Land consolidation is not proposed and boundaries of holdings follow an irregular pattern. The watercourse system is to be constructed Departmentally. However, right-of-way for watercourses is not to be formally acquired by the Department. The work will be carried out on cultivators' lands by agreement with cultivators, the watercourse system being regarded virtually as communal property. In consequence alignments will generally follow boundaries between holdings, unless by special permission of the cultivator in a particular case. The second situation may be encountered in portions of the command of a large project, but is more common in smaller projects where the command is usually in steeper slopes with more irregular topography. Holdings are smaller, and soils are often sharply differentiated between a narrow strip of valley-bottom lands and adjacent valley slopes of lighter often shallow soils. A holding may contain portions of both types. Slopes range up to 4% or more, and erosion is a potential hazard both in watercourses and in water management on the field. In both the cases described mixed cropping (paddy in the wet season and non-paddy in the dry) may be practised in those portions of the command where soils conditions are appropriate. Elsewhere crops in both seasons are non-paddy.

B.4.11 The first case is relatively straightforward. It is illustrated on the accompanying Plate 1. In the second case additional topographic and other factors may call for modification of design priorities (Plates 2, 3, 4).

B.4.12 The area of the outlet command is taken for purposes of illustration as 30 ha, and rate of delivery at the outlet 25 litres/sec (this implies a duty of 0.85 litres/sec/ha as in para B.4.3). The average size of parcel is assumed to be 0.5 ha for a total of 60 parcels within the command. As several different parcels may be owned by one cultivator or family (comprising a holding) the number of cultivators within the command is likely to be less than the number of parcels, and is assumed for present purposes to be 25.

B.4.13 As developed in earlier discussion, the objective in design of the distribution system within the outlet command is that the <u>whole</u> flow at the outlet from the minor (less seepage losses) should be delivered to each farm (in effect each parcel) in turn. A familiar case of such a system is that used in north-western India where rotational supply has been practised since before the turn of the century. There the watercourse extends down to each "survey number", a term designating an individual parcel at the time of earlier cadastral survey, commonly some 2 to 10 ha, usually further

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1/ Legally a "holding" is the total area owned by a family, within a village. It may comprise several "parcels" in different locations within the village or the command.

subdivided in ownership since that survey. Within the survey number further distribution is by informal field channel. Operating procedures in rotational distribution within the watercourse command are well established in the area, and there is no need for further administrative subdivision of the outlet command.

B.4.14 The system referred to above is supported by long-standing tradition, and operates very well. However, it cannot necessarily be directly transposed to areas where the concept of rotational distribution and the coordination between cultivators which it implies are less familiar.

B.4.15 In the latter situation, which is indeed the more general case, the primary issue in design of the distribution system below the outlet is not technical, but administrative. How well will the cultivators served by the common watercourse manage its operation, presuming that Departmental involvement cannot regularly extend below the outlet from the minor? Experience to date in this regard is decidedly mixed, but indicates that considerable initial support is needed if such systems are to operate satisfactorily, both by way of assistance in establishing cultivator groups and by designing the distribution system so as to minimize the span of such groups. As an example, in the case under consideration there are 60 parcels owned by 25 cultivators or families. The 25 cultivators could be regarded as a single administrative group, managing the day-to-day operation of the watercourse system as a whole. Alternatively the outlet command could be considered as divided into five sub-areas each comprising approximately twelve parcels with, on average, some five individual owners (Plate 1). Each such sub-group would manage distribution within its own area, and would also provide a representative for joint planning of management of the watercourse system as a whole. Present consensus favours the latter alternative. Such division of administrative responsibility is facilitated if the watercourse system is so arranged as to provide a separate branch to each of the sub-areas. Where this is done the main stem serving the branches is commonly referred to as the watercourse and the branches as field channels. There is, in effect, a primary rotation from the outlet to each sub-area, in turn, and within each sub-area there is a secondary rotation to the individual farm turnouts. A further advantage of this type of layout is that it makes possible Departmental intervention down to the sub-area level, should this prove necessary initially or through failure of cultivators to manage the system as a whole. The Department then would operate or supervise the operation of the primary rotation down to the five sub-areas and the cultivators would manage the secondary stations within those areas.

B.4.16 A further development of the policy of dividing the outlet command into sub-areas is the practice adopted in some recent projects of providing a lined watercourse down to the turnouts to the sub-areas, and thereafter unlined field channels within the sub-areas. This is referred to as "lining down to the 5 to 8 ha block", 5 to 8 ha being the customary range of size of sub-area in most projects. The practise has considerable merit, although as discussed later there are other criteria also to be considered in determining what portions of a watercourse should be lined in any particular case.

B.4.17 It is assumed for present purposes that the nominally 30 ha area outlet command will in fact be subdivided into five sub-areas. These need not be equal in size, as differing areas can be compensated by differing duration of the periods of rotational supply. It is also assumed that each sub-area will be supplied from the watercourse at one point only (as shown on Plate 1). This is administratively the simplest arrangement, although there are situations discussed later in which more than one point of supply from the watercourse to a sub-area may be indicated (only one of which is in operation at a time).

B.4.18 The task now is to decide the boundaries of the outlet commands within the command of the minor canal, the location of the outlets from the minor, the boundaries of the sub-areas within each outlet command, the alignment of watercourses and field channels and the location of their turnouts, and the location of drainages and farm access routes. In any but the simplest topographic/cadastral situation there are usually several possible alternative arrangements to be compared. There are a number of desirable features in layout, but trade-off between one and another may be necessary and judgement is required in applying design rules or guidelines. Plans of the area to a scale of about 1:4,000 (16 inches to 1 mile) showing property boundaries and also contours at 1 m or 50 cm interval are often used in India for layout. The range of size of outlet command in the case under consideration (para B.4.5) is between 23 and 35 ha. It is convenient to prepare transparent overlays of areas of several shapes (e.g. square, rectangular) representing these upper and lower limits of size to the scale of the base map. The overlays can be moved about on the base-map to assist in initial determination of approximate location of outlet commands. Actual boundaries of the commands will of course follow the individual property lines.

B.4.19 The following are some of the factors to be kept in view in location of the outlet commands and layout of the watercourse systems. As noted earlier it will not generally be possible to conform to all recommendations at the same time; particular local circumstances may dictate a choice or trade-off.

i) Outlets from the minor should preferably be located where the minor is not in deep cut, to avoid a long run of watercourse, also in cut, before commandable area is reached. This consideration should also be kept in view in the original alignment of the minor. Minors are for the purpose of serving watercourses rather than simply for conveyance, and should wherever possible have their full supply level at 30 or 40 cm above adjacent ground level.

ii) The outlet should of course be located so as to permit gravity supply to the whole of the outlet command. If, unavoidably, there are local areas which it will not be possible to serve (i.e which will be "out of command") the cultivators concerned should be made aware of that fact before the layout is finalized.

iii) If possible, widely different soils and drainage situations should not be included in the same outlet command, for instance, valley-slopes of light shallow soils and poorly-drained valley-bottom "wet-lands". Addition of a sub-minor running down-slope to serve an outlet supplying the wet-land area may be a solution. However, where the distance between the minor or other supply canal and the valley bottom is very short (100 to 200 m) this separation may not be possible.

iv) It is convenient if an outlet command lies between two natural drainage lines, with the main stem of the watercourse running down the spur between them. However, this favourable situation is by no means always available. It is possible to carry a watercourse across an active drainage channel (a nullah or wadi) by short length of supported pipe aqueduct if necessary.

v) The cultivators embraced by an outlet command should be a socially compatible group, and preferably coming from the same village.

vi) The above requirement applies even more literally to the cultivators within the sub-areas of the outlet command. It is noted that the sub-areas need not all be equal in size. Inequalities in area are compensated by adjusting the duration of supply from the watercourse. The main consideration is keeping the number of cultivators within the sub-area sufficiently small (preferably less than 15 or 20) and sufficiently socially compatible for amicable management of water distribution within their area.

vii) Design of the layout of the distribution system within the outlet command includes both watercourses and field channels, and extends down to the supply point to <u>every</u> separately-owned parcel. There may be differences in responsibility for construction, as between watercourses and field channels, but the design of the complete system should rest with the Irrigation Department. The location of the turnout or turnouts from the field channel to the parcel is of particular importance to the cultivator in relation to layout of land shaping and farm water distribution, and should be discussed with him during the course of designs.

viii) Watercourses and field channels should follow property boundaries, unless cultivators agree otherwise in particular cases. The reasons for following boundaries are nominally to equalize the loss of area of cultivable land between the cultivators concerned, and to avoid cutting off access from one portion of a field to another by routing a channel across it. Alignment along property boundaries is at the cost of greater length of channel, compared with direct routing regardless of property lines, but cannot generally be avoided. An exception may occur in the case of a large parcel in which it is also convenient to the owner to have a field channel with turnouts traversing his land. Where following boundaries are highly inconvenient or impractical at a particular location a short run of buried pipe may be employed, again with the concurrence of the owner of the property. It is noted that locating a channel centre-line literally along a boundary, to equalize loss of land between neighbours is not technically feasible in some situations, particularly where the neighbouring fields are at considerably different elevations, or the boundary is defined by a row of mature trees, or by a massive stone wall. In such situations the channel may parallel the wall but must be wholly on one side of it.

ix) The provision of watercourses and field channels in an area which is to be largely under paddy in the wet season, and non-paddy crops in the dry, poses particular problems. Paddy cultivation benefits from the existence of a watercourse system, particularly for rotational distribution of full flow during land preparation and puddling. For the remainder of the season the benefits of rotational distribution are less evident, and a small continuous field-to-field flow may indeed be preferred by cultivators. They may consider that a permanent network of field channels supplying each parcel is unnecessary, occupying land which could otherwise be under paddy. Formal field channels are likely to have a short life indeed under these conditions, being ploughed under and replaced by informal farm channels or furrows reconstructed each year by the cultivators after harvesting of paddy. Watercourses may suffer the same fate, which is a more serious matter, amounting to break-down of the dry season rotational distribution system. A compromise in such circumstances is to ensure a permanent, preferably lined watercourse system down to the sub-area and possibly extending into it a short distance, but to omit construction of permanent field channels below that point unless with the concurrence of the cultivators concerned.

B.4.20 The above discussion refers to what was referred to earlier as the "relatively straightforward case". It was noted (para B.4.8) that there is a second situation in which slopes are steeper, soils are shallow and readily erodible, and the command area of the minor or other supply channel is often particularly narrow in width. This is a common situation in small project commands, but it also occurs in portions of larger projects. Much of what has been said earlier is also relevant to the second situation, but design priorities can be significantly different. The situation is described in detail in the paper "Irrigation from Small Tanks". It is consequently discussed here briefly only (see Plates 2, 3, 4).

B.4.21 For purposes of discussion the irrigation duty at the outlet is assumed to be 0.85 litres/sec/ha as in the previous case. However, in view of the erosion problem the rate of delivery at the outlet is reduced to the range 12 to 18 litres/sec. The corresponding limits for size of outlet command are 14 and 21 ha. These figures assume continuous operation of the outlet, 24 hourly 30 days per month, in the peak season. If operation is limited to 12 hours in 24 in the interests of "daylight only" irrigation, (which is possible with very small projects of around 200 ha or less), or if minors are rotated week on/week off even in the peak season in the interests of reducing the size of outlet command, the canal duty at the outlet becomes (2 x 0.85) or 1.7 litres/sec/ha, and the range of size of outlet commands is halved to between 7 and 10.5 ha. As noted later such reduction in size of outlet command may be of advantage in certain cases in the conditions under discussion.

B.4.22 In view of the difficulty experienced by cultivators with on-farm distribution of water in these relatively steep, usually pervious, erodible soils, priority must be given in design of the outlet command to minimizing the length of run of field channels, particularly down-hill runs. The main function of the watercourse in these circumstances is to provide safe down-slope conveyance utilizing a full complement of drop structures or other means of protection against the excess hydraulic gradient (lining, chutes, buried pipe, etc.). The farm channels served by turnouts from the watercourse are then aligned around the contour or are limited to short down-slope runs. Layout of watercourses in such a situation is illustrated in Plate 4. The criterion used in the case shown is that no field should be more than 300 m from a lined watercourse or more than 100 m in slopes of more than 2% or in sandy permeable soils. In such circumstances more than one turnout to a field (one only to be used at a time) may be desirable where a watercourse parallels a down-slope boundary (several cases are shown on Plate 4).

B.4.23 A further example of the type of problem commonly encountered with small irrigation projects is the long narrow command extending down the length of the valley, bounded between the river and the supply canal. Width of the outlet command between canal and river may be as little as 150 m, with corresponding length in the direction parallel to the canal of nearly 1,000 m. As discussed in para B.4.21, the size of the outlet command, and its length, may be halved by designing the minor or other supply canal for 50% on/50% off rotation, but this may still leave an outlet command extending some 500 m down the length of the valley. As the soils in this situation are generally light-textured and permeable, and on cross-valley slopes of 3% or more, the criterion referred to in para B.4.22 requires a lined watercourse paralleling the minor for at least 400 m, serving each of the parcels along its length (see Plate 2). This again is a case in which the operational simplicity of a single outlet from a watercourse serving a "5 to 8 ha" sub-area must be foregone, in view of the advantage of direct supply from the lined watercourse to the individual parcel. However, both in this case and in that discussed in para B.4.22, the outlet command can still be divided into sub-areas as far as organization of cultivators is concerned.

B.4.24 A similar case to that discussed above may be encountered when a minor canal runs down a spur, with its command on either side as shown on Plate 3, Fig. 1. The options available are the following:

a) As shown on Fig. 2, to run a watercourse on either side of the minor, each serving an area (in the case shown) of 40 ha. The two outlets then run with the minor, no rotation being required. This is the most satisfactory solution, operationally, but requires three parallel channels running down the spur. This would be best provided by a composite flume section, with the minor in the centre and a structurally integral watercourse on either side.

b) As shown on Fig. 3, serve each of the sub-areas by direct outlet from the minor. As the sub-areas would be too small for continuous supply at the minimum efficient rate, rotational operation of their outlets would be necessary. This is undesirable operationally but avoids the need for parallel channels.

c) The same arrangement as in Fig. 3, but the minor is operated rotationally on the distributary, for instance one-third on/two-thirds off in the peak season. All the outlets then operate with the minor, and rotation of outlets is unnecessary. The capacity of the minor would have to be increased by a factor of three, compared with the other two cases. However, the main disadvantage is the need to rotate the minor on the distributary.

B.4.25 All three options are viable. Choice in any particular case would involve trade-off between operational simplicity and first cost.

Consolidation of Holdings in Relation to Watercourse Layout

B.4.26 The advantages of consolidation of the scattered parcels which make up a holding into one or more compact units have been referred to earlier. It greatly facilitates layout of the watercourse system, provision of farm access, land shaping for irrigation, and cultivation (particularly the use of mechanical equipment). With such obvious advantages it might be considered that consolidation of holdings should be made a pre-condition for an irrigation project. There are, indeed, situations in which such a position would be warranted, and probably welcomed by cultivators. However, it must be acknowledged that there are also situations in which the reverse is the case. The most common is due to considerable differences in soil depth and fertility between neighbouring plots. This occurs in rolling topography with often very shallow soils over granular substructure on the uplands and valley slopes, and relatively deep (transported) soils in valley bottom areas. With prolonged tillage a particular cultivator and his forbears may have deepened and built up the fertility of his upland plot. The neighbouring plot may not have received such attention. In such circumstances any suggestion of exchange of one area for another in the interests of consolidation is likely to be strongly resisted. Further in such areas holdings are frequently divided into narrow down-slope strips so that each inheritor has an equal proportion of shallow upland soils and fertile valley-bottom soils. While most inconvenient for purposes of irrigation, the system has merit from the viewpoint of equity in inheritance, and any attempt to change the status is not likely to be welcomed. In similar circumstances cultivators may have purposely acquired separate plots in areas of different soil type for the purpose of raising different types of crop (for instance an area suited to paddy, and other areas for up-land crops).

B.4.27 In areas of uniform deep soils the above problems do not arise, and consolidation may be quite acceptable to cultivators. However, even in these circumstances strong resistance to consolidation has been encountered in at least one major area due to uncertainty or lack of confidence regarding land titles and unwillingness to have them exposed to scrutiny.

B.4.28 To summarize, consolidation of holdings has obvious merits in development of an area for irrigation, but there are strong contrary arguments in some situations. Consolidation can be carried out only if cultivators can be persuaded that it is in their interests. Otherwise land development for irrigation must proceed in the context of the existing property holdings.

Extent of Lining of Watercourses

B.4.29 While it is generally agreed that lining of watercourses makes for improved efficiency of water distribution and enhanced development of an irrigation area, the question of the extent of lining justified in a particular case can be much debated. Reasons for lining may include the following:

a) Reduction of seepage loss. Seepage from a watercourse may represent an economic loss of water, or an unwanted contribution to an incipient waterlogging problem.

b) Improved reliability of supply, and rate of delivery, to "tail-end" areas on a watercourse.

c) Avoidance of weed infestation in unlined channels.

d) In steeply sloping areas, lining (particularly a lined chute), may be an economic alternative to closely-spaced drop structures on an unlined channel.

B.4.30 Of the above benefits reduction in loss through seepage is possibly the simplest to evaluate. However not all channel seepage is necessarily lost, as a proportion may be recovered from groundwater by tubewells, provided that the groundwater is of usable quality. On the other hand a considerable proportion may be lost through plant transpiration or evaporation from waterlogged areas adjacent to the channel, and is not recoverable.

B.4.31 The annual seepage loss per unit of channel length is influenced by the amount of time during which a particular reach of the channel is in use. In a branching watercourse supplying rotationally, the upstream "main stem" may be flowing near-continuously, whereas a particular downstream branch may be in use for a few hours only per week. The amount of water saved per unit length of lining is consequently greater in upper reaches than lower. The physical conditions at the upstream end of a watercourse, where low-lying borrow-areas adjacent to the parent canal may have to be crossed on embankment, also give emphasis to lining in that area.

B.4.32 The effects of improved reliability of supply due to lining, such as freedom from breaches (accidental or intentional) and the substantially greater flow delivered to "tail-end" areas particularly in high infiltration soils, are difficult to estimate other than by reference to relative levels of crop production in lined and unlined areas elsewhere. Benefits from lining in this respect can be substantial.

B.4.33 Weed infestation in an unlined channel can be a major problem if the channel is in operation throughout the year, without the natural weed-control otherwise provided by a period out of service in the hot weather. Reed growth flourishes in such perennially wet conditions and may be a principal reason for channel lining.

B.4.34 It is evident from the above discussion that the economic evaluation of watercourse lining is very case-specific, and is not at all straight-forward. Furthermore the decision on whether to line, or how much to line, is likely to be influenced as much by financial as by economic considerations. This is particularly the case where cultivators are to meet part or all of the cost of lining, and willingness or ability to pay that cost may be a primary factor in the decision.

Right-of-Way for Watercourses

B.4.35 Practices in respect of right-of-way acquisition vary. In some cases the right-of-way is procured by the Irrigation Department and the watercourse is regarded as a Departmental channel, although maintained by the cultivators which it serves. In other cases the watercourse is regarded as a communal facility and right-of-way is provided by the beneficiaries without cost. It is essential in the latter case that the position be covered by appropriate legislation, such as a Land Conservation Act or a Command Area Development Act, providing for construction of the works on privately held lands.

Farm Access Within the Outlet Command

B.4.36 Access to individual farm plots within a typical 30 to 40 ha of smallholdings under rainfed cultivation is partly by customary village pathways or tracks and partly across fields. There is usually no formal access to each farm. Tradition plays a considerable part in the provision of access across neighbours' fields, and agricultural activities may have to be coordinated, particularly harvesting, to facilitate such access. With the prospect of irrigation in such an area the case for more formal access to each farm, permitting passage of wheeled equipment at any time, needs consideration. Where land consolidation is to be carried out such access-routes may be provided for in that process. However, as discussed earlier, consolidation is likely to be the exception rather than the rule. In any case small cultivators are usually most reluctant to take land out of production to provide permanent access. There is a clear conflict between the advantage of unimpeded access, particularly for wheeled vehicles, and the loss of cultivable land which provision of such access would entail.

B.4.37 Construction of the irrigation system affects the access situation in several respects. A maintenance path paralleling the minor canal is in any case necessary, and there is much to be said for making this of adequate width for small wheeled vehicles (including Departmental jeeps) and permitting its use by cultivators in the area, including passage by bullock-wagons and tractors. Bridges should be provided wherever the minor crosses a traditional village access-way. Watercourses, whether on Departmental or communal right-of-way, should have a pathway on the embankment on one or both sides, which is open to public use, although not generally of sufficient width for wheeled vehicles. It is essential that culvert crossings be provided on watercourses wherever they intersect traditional village tracks and wherever necessary to provide access to a farm. Lack of a formal crossing, where needed, usually results in an informal crossing and damage to the watercourse, particularly if lined.

B.4.38 As access is a matter of considerable importance to villagers and cultivators in an area to be brought under irrigation, they should be given opportunity to discuss plans and contribute suggestions before layouts are finalized.

Drainage

B.4.39 Drainage of irrigation areas in general is discussed in Paper A. The following comments are confined to drainage within the outlet command. Two situations may be encountered:

a) Near-flat topography, with holdings consolidated into a regular rectangular pattern.

b) The more general case of gently rolling topography with smallholdings, not consolidated.

The first situation permits use of the classic rectangular layout of watercourses and associated drainage ditches, bounding large rectangular fields. The second situation requires a much more pragmatic approach to drainage design.

B.4.40 The importance of adequate drainage in irrigated areas is acknowledged, but it must be recognized that maintenance of drainage channels at the farm level is usually given little priority by the cultivator. Furthermore weed infestation of collector drains can be a major problem and beyond the resources allocated for clearance and removal. Maximum use should be made of natural topographic drainage. First priority should be given to improving or clearing of obstructions from primary drainage, without which back-up of water may occur on to agricultural lands in spite of efforts at field drainage. Flow across fields may be acceptable in periods of heavy precipitation but prolonged impondment due to downstream obstruction is not. All fields should have a storm drainage outflow route, even if across adjacent fields, and ditch construction or local land shaping to ensure such outflow should be undertaken where necessary.

B.4.41 Aside from storm-water drainage discussed above, irrigation introduces its own drainage problems. These include accumulation of irrigation spill from fields and from watercourses in low areas, also deterioration or flooding of road embankments due to seepages or spill. As these situations are likely to be of more regular occurrence than storm drainage they should be given particular attention in project design. All watercourses should have facility for tail-end spill and conveyance of flow into a natural water-way. Attention should also be given to provision of road-side ditches and culverts and where necessary to raising of road embankments.

B.4.42 To summarize, where there is an appreciable natural pattern of topographic drainage maximum use should be made of it. New drainage construction should be selective, rather than on an arbitrary pattern. Where there is little or no natural drainage gradient construction of primary and secondary drains is of first priority. In view of the problems of drainage maintenance these too should be laid out very selectively.

B.5 CONTROL STRUCTURES AND CHANNEL LININGS FOR WATERCOURSES

The Outlet from the Minor Canal

B.5.1 Determination of the capacity of an outlet to a watercourse has been discussed earlier. A typical minor canal may have ten or more outlets, each of capacity matching the area of its command but lying within the acceptable range of delivery stream for the particular situation (for instance 20 to 30 litres/sec). While there could be some advantage in designing outlets to be adjustable in capacity, experience generally is that it is impossible to control unauthorized tampering, and that outlets once installed should be of fixed capacity. For example, Adjustable Proportional Modules (APMs), as used widely in north-western India, can only be adjusted before they are installed; after installation they are only capable of being changed if the outlet block is removed and replaced. The APM is reputed to also divert an appropriate share of the silt conveyed by the minor canal.

B.5.2 The total capacity of the outlets on a minor must of course equal the capacity of the minor itself (with due allowance for seepage losses), at its upstream end. The function of the outlets is to divide the flow in the minor in proportion to their nominal individual capacities, with the minor running at its design capacity or within a range of some 25% either side of it, and without adjustment of outlets. The possible types of outlet include the following:

a) A flow divider

b) A simple weir

c) A simple orifice

d) A combination of weir and orifice (functions as a weir at low levels in the minor and as an orifice at higher levels)

e) An orifice with shaped baffles to change its discharge coefficient with rising level in the minor, the outflow remaining near-constant.

B.5.3 The flow divider performs the task of dividing the flow in the minor between the outlets very effectively, virtually regardless of that flow. It requires a simple weir across the minor at each outlet, with sufficient drop in water level to ensure "critical flow" conditions. A vertical dividing wall placed at the appropriate location on the weir crest divides the flow in the proportion required. One portion continues downstream to the next divider; the other is diverted to the watercourse. The flow divider system is particularly appropriate to small minors with relatively few (e.g. to five or six) outlets. Its limitations are the cost of the structure for larger capacity minors, and the fact that sufficient head must be available for critical flow conditions (i.e. a hydraulic drop) at each weir.

B.5.4 The simple weir outlet is seldom used as the discharge is very sensitive to head on the weir (i.e. to level in the minor). Any variation in level from design values, down the length of the minor, or any inaccuracy in setting of weir elevation, could cause inequality in division of flow.

B.5.5 The remaining three alternatives (c), (d) and (e) are variations of the orifice. The baffled orifice is an ingenious device designed to give near-constant discharge regardless of level in the supply channel (within limits). In a closely regulated system in which the flow in the minor does not vary from its design value the baffled orifice could have value as an outlet. However, where the flow in the minor may vary from design value, intentionally or otherwise, proportional flow to outlets is desirable rather than fixed flow, and use of the baffled orifice would be inappropriate in such circumstances. In fact the baffled orifice (singly or in groups) is most frequently used as a head-gate to control flow to a minor.

B.5.6 The simple orifice (Plate 5 is typical) has the advantage over a weir of being less sensitive to head, in this case to level in the minor. As the discharge through an orifice is proportional to the square root of head a change of 10% in head produces a change of only 5% in discharge. The higher the head on the orifice, 1/ the less sensitive is the discharge in the individual outlet to a minor variation in fully supply level (FSL) from the design value (for instance due to siltation or weed growth). On the other hand it is desirable that the discharge in the outlets <u>should</u> increase to accommodate an intentional increase in flow in the minor of up to 25% of its capacity, without excessive ponding up in the minor and encroachment on freeboard. For instance if an orifice-type outlet is set at

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1/ Provided that the orifice is discharging under "non-submerged" conditions.

15 cm below normal FSL in the minor, for its capacity to increase by 25% would require an increase in head of 56% or approximately 8 cm increase in level in the minor. This would normally be within the increase in level in the minor corresponding to the 25% increase in flow.

B.5.7 It is possible to design a canal section and the depth of setting of the outlet so as to achieve proportionality between flow in the canal and flow in the outlet, at least over a small range in head. However, other factors intervene in canal design, and the degree of proportionality achieved is approximate only. It must be recognized that in the trade-off between precision in regulation of flow to outlets from the minor, and robust simplicity of design, the latter must prevail in the conditions under discussion.

B.5.8 Additional items to be considered in the design of outlets are gates and flow measurement. In the recommended situation the outlets are designed to operate together with the minor, avoiding rotation of outlets. In these circumstances the outlets always remain open unless for short-term reasons. Provision should nevertheless be made for closure of an outlet, but preferably by simple means not prone to theft. Leakage at the closure is not a main consideration in these circumstances. In the arrangement shown on Plate 5 closure is provided by a simple concrete slab. Measurement of flow at an outlet is a perennial problem. At least an approximate indication of flow, meaningful to the farmer, is desirable. However, conventional devices such as measuring flumes and weirs installed at outlets commonly have short life, being removed by cultivators who regard them as obstructions to flow, or for other reasons. In the arrangement shown on Plate 5 the depth of flow at the downstream end of the culvert pipe is an indicator of flow (provided that flow is not submerged) and could be formalized by inscribing a scale. The discharge at each outlet under normal operating conditions in the minor should be checked, at least during initial commissioning, by portable flume or weir such as shown on Plate 6.

Turnouts, Drops, Check Structures

B.5.9 Control of water distribution within the outlet command requires gates at principal branches and at every farm turnout. As there may be fifty or more turnouts their design and cost is of considerable importance. Leakage at gates and turnouts is also an important factor, in view of the number of them which may be closed against head at any time. In the simplest systems a turnout from an unlined channel may be simply a branching channel, closed when not in use by earth. Gates on branches in such simple systems may also be substituted simply by temporary earth filling. However, permanent structures are highly desirable at each principal branch in the watercourse, and preferably at each turnout. A problem with such structures is theft of gates, particularly if of metal or wood. A simple precast concrete structure which may be used at branches, turnouts and checks in unlined watercourses is shown on Plate 7. This uses a precast concrete slab for closure, but is also designed to facilitate closure by brushwood and earth if the gate slab is stolen. Another system is the precast concrete "pucca nakka" in which the "gate" is a circular precast concrete plate ground to fit a circular seat in the concrete frame, the latter being encased in brickwork. This provides a tight seal, and the circular concrete plate is apparently sufficiently conspicuously designed for its purpose that theft is not a major problem.

B.5.10 Drop structures can be a major cost item in steeply sloping topography. The use of sloping runs of lined channel in place of conventional masonry or brickwork drops is increasingly favoured. For long down-slope runs of 4% gradient or steeper a continuous lined channel with stepped floor (an energy dissipating chute) is likely to be lower in cost than a series of masonry drops on an unlined channel. As discussed later, buried pipe running down-slope between intermediate brickwork or masonry open cisterns (for turnouts) can also be an effective alternative.

Types of Lining for Watercourses

B.5.11 Types of lining used for watercourses include:

- Rectangular brick
- Composite concrete floor and vertical brick sides
- Precast concrete integral trapezoidal sections (extrusion process)
- Precast concrete semicircular sections (spun process)
- Precast concrete slabs or tiles lining a trapezoidal excavated channel, with or without polythene sheet behind the slabs.
- Natural stone slabs lining trapezoidal channel, with various combinations of polythene and cement-mortar backing
- Brick tiles lining trapezoidal channel, with polythene and/or cement mortar backing.

Selection for a particular location is influenced by availability of material, particularly concrete aggregate versus brick-making clays. The nature of the soils of the project area, notably the presence or absence of expansive (cracking) clays, can also influence choice, favouring structural flexibility. Cost is a factor, but durability of lining is more important. Linings are discussed in detail in Annex B1.

Use of Buried Pipe in Watercourse Systems

B.5.12 There are a number of situations in which the use of buried pipe in place of open channel for distribution from the minor canal outlet can be attractive, and warrants consideration. They include the following:

a) Very small holdings in which right-of-way for open channels is a major problem

b) High land values, particularly in areas of prospective urbanization

c) Desert areas where wind-blown sand may fill or cover open channels overnight, and wind may erode support for such channels

d) Steeply sloping areas, typically 4% and above, where the gradient may be used to advantage in relatively small size of pipe. The need for drop structures is also avoided.

e) As in (d), where the gravity head available may permit final delivery by hose or sprinkler or other such pressure system.

B.5.13 The first situation may occur in areas of relatively flat topography, in which little head is available (0.5 m or less) between the level in the supply canal at the outlet and the farthest point of the outlet command. Pipe sizes required are relatively larger than in sloping topography, but solutions can be worked out either using PVC pipe (light-walled agricultural pipe) or a combination of low-pressure concrete pipe and PVC laterals. Such systems are now being proposed for construction.

B.5.14 In situation (d) and (e) the more steeply graded topography considerably facilitates the use of pipe for conveyance, and conversely adds to the cost of the alternative of open channel. The advantages of delivery under pressure from the pipe system can be major, particularly in horticultural areas.

B.5.15 The subject is covered in detail in Paper D in Volume II.

B.6 ON-FARM DEVELOPMENT FOR IRRIGATION

Land Shaping, Institutional and by Cultivator

B.6.1 As discussed earlier, many aspects of land development for irrigation, including land shaping, are simplified if holdings are consolidated. However, as consolidation is by no means everywhere practised in Asian smallholder agriculture the subject of land shaping is discussed on the basis of the individual holding as the unit.

B.6.2 Views on the relative merits of land shaping institutionally versus by the cultivator vary. It can be argued that expeditious land shaping by mechanical equipment through institutional credit is economically desirable and is in the interests of the cultivator. On the other hand poor experience in recovery of loans for land shaping and the reluctance of cultivators to undertake such debt argue for accepting the longer time of land development when carried out by the cultivator himself. The following factors are relevant:

- The difficulty of the task, particularly whether clearing of heavy timber, is involved. If so, clearing and possibly rough levelling should probably be carried out by contract.

- The size of the holding. A relatively large holding (5 ha or more in the present context) would suggest that the time taken for land shaping through a cultivator's own resources, possibly limited to bullock and plough, would be excessive. On the other hand a cultivator with such a holding may be at subsistence level under rainfed conditions, and the indebtedness he would be faced with in having his entire holding levelled by contract and in launching into irrigated cropping of the whole area would appear to him to be enormous. Regardless of project economics the cultivator is under no personal obligation to embark on such an undertaking. He would probably prefer to bring his land under irrigation slowly, increasing the developed area progressively.

- Topography, soil depth. Gently rolling topography and deep soils lend themselves to relatively large scale levelling by heavy equipment. On the other hand, steeper grades and shallow soils require very careful handling in land shaping, to avoid exposure of infertile subsoil. Lighter equipment (small tractor with scraper blade) or progressive development by the cultivator, beginning with contour furrowing only, may be indicated.

B.6.3 In the final analysis the decision whether to embark on full-scale land shaping through institutional credit or to carry out land development more slowly with his own resources will rest with the cultivator. In either case he should be given advice and assistance in the design and execution of his land shaping plans. The quality of the final product also rests with the cultivator, as shaping by heavy equipment still leaves the problem of differential settlement between areas of cut and fill subsequent to shaping, unless the equipment is brought back to do final levelling after a season of irrigation, an unusual event in the area under discussion.

Form of Land Shaping, and Cultivation Practices for Water Management

B.6.4 The following options are available in preparation of land for irrigation:

a) The flat basin, or series of basins. This may consist of a large rectangular flat field irrigated either as a unit or sub-divided by temporary ridges or checks, or flat terraces (which may be as small as 1 or 2 m in width), or terraces divided into small individual basins stepped around a "sloping contour", or simply very many small basins each only a few square metres in area. It is the only option where flooded paddy is to be grown. When crops other than paddy are being grown in a flat basin, the level-furrow or "furrow-in-a-basin" method of land preparation may be used, or more widely spaced distribution furrows, in some cases amounting to raised level beds with intervening drainage/irrigation ditches. The flat basin, in one of its variations, can be used in almost any circumstance, with the reservation that in very heavy soils in monsoonal conditions surface drainage must also be provided within the field, by furrows connecting to perimeter ditches. Irrigation by flat basins can be highly efficient. It is the most common form of land shaping in Asia and is being used increasingly in some western countries (including the U.S.) on very large fields levelled with the assistance of laser beams, in the interests of maximum distribution efficiency and minimum labour cost in water management.

b) Graded strips or graded furrows. As applied to large-scale irrigation a field prepared for graded strip or graded furrow irrigation is usually rectangular in shape and uniformly graded from upper to lower end. Where ridge and furrow cultivation is not employed the field is usually divided into strips by small ridges to facilitate water management. Water is admitted at the upper end and flows progressively towards the lower, the supply being cut off while the advancing stream is still some distance from the lower end of the field. If timed correctly the stream continues down to the lower boundary before flow finally ceases. There is considerable literature on the subject of appropriate gradient, rate of water application, and infiltration rate, etc. At a less sophisticated level is the graded "sloping contour" furrow or series of furrows, or graded contour terraces. In small-scale irrigation of steeply sloping irregular topography furrows may zig-zag down the slope with flow control exercised by earthen checks.

c) Although not yet widely used in Asian smallholder agriculture, a third option is to avoid land shaping entirely (other than smoothing) by the use of sprinkler, or trickle, or hose, or similar type of water application system.

B.6.5 Choice of land shaping system adopted in a particular case is likely to be influenced by:

- The crops to be grown (particularly if wet land paddy).
- Topography and soil depth. Soil infiltration rate.
- The size of holding.
- The financial resources of the cultivator, and the relative importance of capital cost of land preparation versus labour cost in water management in irrigation.

B.6.6 For the small cultivator there is much to be said for progressive land development, beginning with small basins, or contour furrowing if the topography so indicates, and year by year graduating to larger basins, or from contour furrows to contour terraces, and from narrow to wider terraces. For the cultivator with adequate resources final development in one step, using mechanical equipment, may be preferable. However, the need to avoid over-excavation and loss of fertility in shallow soils is a primary constraint in use of heavy mechanical land-shaping.

Farm Channels

B.6.7 Construction of distribution channels on the farm is clearly the responsibility of the cultivator. In reasonably flat topography this does not present any difficulty. In steeper slopes or irregular topography, however, on-farm distribution can present some of the problems of a larger irrigation system. In particular, drop structures may be needed if erosion of channels to below command level is to be avoided. The design of the farm channel system, and associated land shaping, may be beyond the capabilities of a small cultivator previously accustomed to rainfed agriculture only. He is likely to proceed slowly, by trial and error, and a poor standard of irrigation efficiency is likely to result, certainly in the early years. Advice and demonstration in farm development for irrigation are most desirable at this time. However, staff capable of giving such assistance are not generally available, either from Irrigation Department or from Agricultural Extension. It is an area much in need of attention.

B.7 PARTICIPATION OF CULTIVATORS IN CONSTRUCTION AND MAINTENANCE OF THE WATERCOURSE/FIELD CHANNEL SYSTEM

Coordination with Cultivators in Location of Outlets from Minors, Boundaries of Outlet Commands, and Layout of Watercourses

B.7.1 While the boundary between the Irrigation Department and the cultivator is nominally the outlet from the minor canal, it is apparent that the design and execution of the distribution system below the outlet, as now conceived, also requires some Departmental participation. The problem is how to provide such assistance without detracting from the position of communal ownership and responsibility for the facilities. It is no longer considered adequate for the Department to end its activities at the outlet and to leave all else below that to the cultivators. On the other hand the attitude "Government built it so Government can maintain it" is very common among cultivators, who in any case generally prefer construction of facilities at Government expense rather than their own.

B.7.2 In this conflicting situation it is essential that whatever the Department does within the outlet command should be done correctly, both technically and from the user (cultivator) viewpoint, and this involves consultation with cultivators.

B.7.3 Such consultation is not a simple process, for several reasons. Cultivators are not yet organized at that stage, with accepted spokesmen; tenants cannot speak for absent landlords; furthermore cultivators whose previous experience is entirely rainfed are not always in a position to forsee their needs under irrigation. Nevertheless consultation must take place, and to be productive it must be based on specific proposals. The position of outlets should be flagged, also boundaries of the outlet commands, the alignment of watercourses and field channels, and the suggested location of turnouts to individual farms. Formal village meetings should be called after cultivators have had time to discuss flagged alignments among themselves, and to develop comments or suggestions.

Possible Participation of Cultivators in Construction of Watercourses and Field Channels

B.7.4 While Departmental assistance in <u>design</u> of the distribution system should extend down to the turnout to the individual farm, there is a case for maximum possible participation of cultivators in its <u>construction</u>. Where distinction is made between delivery down to the "5 to 8 ha" sub-area (by watercourse), and within that area (by field channel), construction of the field channel system could in most circumstances be left entirely to the cultivators which it serves, provided that the structures required (if pre-cast) should be furnished by the Department. In the case of the watercourse itself, or the main stem if no distinction is made betweeen watercourse and field channel, the position is less clear. Generally a proportion of the channel will be lined, involving procurement and installation of lining material, and also structures. This requires more skill than simple channel excavation. Lining <u>has</u> been successfully carried out by cultivators, but most often construction is by contractor or Departmentally. Cultivators may participate informally in the latter case as hired labour.

Maintenance of Watercourses

B.7.5 Although the Irrigation Department may be involved in construction of watercourses in one capacity or another, maintenance should be by the cultivators only. Where the channel is unlined maintenance consists simply of removal of silt and weeds. This should not present any difficulty to the cultivators concerned, provided that they are organized into an effective water users association. However, recent experience has shown that organization of cultivators for an effective campaign of watercourse rehabilitation does not necessarily ensure that the organization will continue to function for subsequent maintenance.

B.7.6 Where a watercourse is lined for part of its length maintenance should be much reduced, but will nevertheless involve use of materials such as cement, sand, brick, etc. which are not immediately available to the continueor. Formal structures (turnouts, drops, etc.) are in the same category. In such circumstances Departmental assistance in maintenance may be necesssary, if only to the extent of providing materials.

B.8 OPERATION OF THE MINOR OUTLET AND THE WATERCOURSE SYSTEM. COORDINATION BETWEEN CULTIVATORS AND THE IRRIGATION DEPARTMENT

Scheduling of Supply to the Outlet from the Minor Canal, and Within the Outlet Command

B.8.1 Scheduling of supply to the outlet, and within the outlet command to the individual cultivator, is the most debated topic in smallholder irrigation. In an ideal situation with inflow to the project and delivery entirely predictable, and with all cultivators adhering to a standard cropping pattern, scheduling of supply would be relatively straightforward. However, in many projects the situation is complicated by the fact that:

- Availability of water is variable from year to year, also within the season.

- Cultivators generally have some freedom in selecting the crops they wish to grow.

- While the Irrigation Department has control over the outlet from the minor, control over individual turnouts from the watercourse or field channel is outside the control of the Department and rests with the cultivators themselves.

- Not all of an outlet command is levelled or otherwise ready to receive irrigation when water is first delivered to it. Irrigation may be taken up progressively over several years, requiring frequent revision to scheduling of distribution within the outlet command.

B.8.2 Other than in the simplest situation flexibility and cooperation between all concerned is obviously necessary. A principal question is to what extent the cultivators are prepared to exercise the required cooperation, and down to what level Departmental intervention is necessary. Ideally the cultivators supplied by an outlet would function as a Water-Users Association, taking water from the Irrigation Department at the outlet from the minor canal and distributing it among the members of the

Association, subject only to regulations concerning individual entitlement and payment for water. The inter-face between the Department and the cultivators would then be at the Minor Canal Committee level, at which representatives of each outlet Association would work with the Department in planning the release of available water to the minor, and meeting emergency supply situations as they arose.

B.8.3 Unfortunately a typical group of fifty or more small cultivators, previously rainfed, and joined for the first time under a common irrigation outlet, is not generally ready to take up cooperative management of irrigation supply, at least not immediately. Outside authority, in the form of Irrigation Department, Command Area Development Authority, or Agricultural Extension, is usually necessary initially, and indeed is frequently requested by cultivators.

B.8.4 Even where such "Government" assistance is requested, however, it should be at the minimum level. With division of an outlet command into "5 to 8 ha" operational sub-areas, and with appointment of water-men by the cultivators within each sub area or within the outlet command as a whole, the Departmental or other intervention can be restricted to assistance in organization and supervision of scheduling.

Exchange of Water between Cultivators

B.8.5 Formal scheduling of fixed rotational supply to individual cultivators is possible in a simple situation. For most effective use of water, however, exchanges between neighbours are most desirable and the more diversified the cropping pattern the more necessary such flexibility becomes. The Water Users Association provides such flexibility, and is the administrative system to be eventually aimed at.

B.9 MONITORING AND EVALUATION OF PERFORMANCE AT THE LEVEL OF THE OUTLET COMMAND

The Purpose of Monitoring and Evaluation in Irrigation Development. The Outlet Command as the Focus of M & E

B.9.1 A canal irrigation project, in the context of engineering for smallholder agriculture, can be regarded as having two parts:

a) A facility for regulation and supply of water to the outlets from the main canal system.

b) Irrigation development in the group of smallholdings supplied by each outlet.

Item (a) is primarily a matter of engineering technology. Item (b) is very much concerned with the cultivator, individually and communally, his endeavours at development of his farm for irrigated agriculture, his attitude towards group management of the water supplied from the outlet, and the financial and social impact of the project on his family.

B.9.2 Monitoring of development of an irrigation project covers physical progress on items included in (a) and (b), together with progress on farm development, establishment of cultivator organizations for water management, and a number of other less quantifiable factors.

B.9.3 As a project comes into service progressively during the construction period, and in subsequent years, evaluation of performance becomes of primary interest. The outlet command and what goes on within its boundaries is the obvious unit for evaluation of production, and of project impact.

B.9.4 Monitoring and evaluation serve two purposes:

1) Continuing review of progress and expenditures required for periodic reporting to Government and to lending agencies (Monitoring).

2) Analysis of the physical performance of the project, and its impact on the beneficiary group, to provide Government with means of control (and re-direction of priorities if necessary) during project execution, and for guidance in development of policies for further irrigation development (Evaluation).

Items to be Covered in Monitoring and Evaluation

B.9.5 While the design of the storage dam and canal system of an irrigation project may be largely completed before execution of the project is undertaken, this is not the case with development of the outlet command. The latter should be designed in principle before a project is launched, but finalization of layouts within each individual command must usually await topographic and cadastral surveys which are not normally available in detail at the time of project appraisal. It must also await exchange of views with the cultivator, which is not possible at meaningful level until work has visibly begun on the main canal system and cultivators are convinced of the imminence of supply of water.

B.9.6 In the circumstances progress reporting at the level of the outlet command covers a number of items other than physical construction. These include the following:

- Contour surveying (generally 0.3 m interval) for detailed design of outlet distribution systems.

- Up-dating of village maps (Revenue Department) to show boundaries of present holdings and registered owners.

- Soil surveying.

- Establishment of legal basis for construction of command watercourse system (Command Area Development Act or other legislation).

- Detailed design of watercourse/field channel systems for selected outlet commands, as a basis for establishing design criteria for the remainder of the project.

- Progress on design of layouts of watercourses, and flagging and review with cultivators.

- Progress on execution of watercourse/field channel systems.

- Discussion of land shaping with cultivators, and setting up of arrangements for institutional finance for land shaping where desired.

- Establishment of water-user groups at the outlet command or sub-area level.

- Progress on land preparation for irrigation (by cultivators or otherwise).

B.9.7 Actual irrigation in the upstream area of the project command may begin well in advance of project completion, and evaluation should be initiated as soon as possible thereafter, with base-line surveys in selected areas completed before the start of construction. Evaluation should cover both physical performance and financial and sociological impact. While the latter may take some time to be fully evident the parameters or indicators to be used should be established at the time of the base-line survey. Physical performance should include the following:

- Actual rate of delivery from outlet, and comparison with deliveries at other outlets on the minor (including "tail-end" outlets).

- Actual rate of delivery at turnouts on the outer perimeter of the watercourse system.

- Efficiency of field distribution within the farm (field channel losses). (The above three items will require the use of a portable flume or weir. A schematic design for a portable weir for use in unlined channels is shown on Plate 6).

- Actual seasonal water application by cultivators, on representative crops.

- Seepage rates from paddy fields.

- Seasonal depth to water-table at selected locations, and observation of progressive changes.

- Agricultural production from selected outlet commands, with record of inputs. Farm budgets.

- Equity in distribution of water between cultivators served by an outlet.

- Responsiveness of supply from the minor to crop water needs.

- Effectiveness of operation of water-users associations.

B.9.8 Monitoring and evaluation of irrigation projects and effective feed-back of information from M and E to continuing construction or operational activities are currently subjects of considerable interest to financing and executing agencies. Guidelines for monitoring and evaluation of irrigation projects are in course of preparation under the sponsorship of IFAD (International Fund for Agricultural Development).

LININGS FOR WATERCOURSES AND MINOR CANALS

Introduction

1. The basic construction materials are brick, stone-slab, and concrete, either alone or in association with polyethylene or other plastic sheet. For smaller channels there are the options of sloping sides supported on the lateral fill or excavation, or structurally self-supporting (including vertical) sides in which the lateral fill does not directly contribute to support of the lining. Finally, plastic sheet may be employed simply as an aid to construction, or it may be used as the primary water-retaining element, the remainder of the lining (brick, stone, or concrete) functioning mainly to protect the plastic sheet.

Rectangular Brick Linings

2. The rectangular vertical-sided channel constructed of brick, wall thickness, 4.5 or 9 inches when above a certain height, is very widely used and can be quite effective. Variations include the use of concrete rather than brick for the floor of the channel, inside plastering or plain, and the use of plastic sheet behind the lining. With the price of bricks in the range of Rs400 to Rs500 per 1,000, 1/ and relatively high daily wage rates for masons, brick lining is no longer necessarily the cheapest alternative. However, it is an obvious contender where good quality bricks are available.

3. Problems which may be encountered in the use of rectangular brick channels include the following:

- It is a very rigid lining. Cracking and deterioration are likely if the fill on which the floor of the channel is placed (in embankment section) is not fully compacted, also in expansive clay soils where differential movement can be expected. The use of a plastic sheet behind the lining (bottom and sides) can reduce seepage from cracking, and also the accelerated differential settlement which may result from seepage. (The questions of thickness of plastic sheet and problems associated with its use are discussed later.)

- In even moderately expansive soils lateral pressure from the fill on either side can damage or displace the vertical walls of the lining. This problem can be reduced by keeping the width of the fill as narrow as possible (not more than 30 cm at the top in such soils, so that lateral pressure from the fill cannot build up). When the channel is in cut in expansive soils the back-fill against the lining, and for a width of at least 15 cm, should be of imported non-expansive material. However, in heavily expansive soils brick channels are not a satisfactory solution.

- Cement for mortar is a principal item of cost in brick work, and unless there is close supervision poor quality mortar may be used. Bricks may later be easily dislodged or removed.

1/ Indian Rupees, 1985: Rs11.80 = US$1.

- Rate of construction of brick channels is relatively slow, a disadvantage if the construction season is limited to a few months only. This is a particular factor where existing unlined watercourses are to be lined in the "off" months of irrigation.

- As normally constructed, rectangular brick channels have fill extending up to the top of the channel, where a narrow foot-way is provided on either side. This is convenient in most circumstances, although the lateral fill is not necessary to support the walls of the lining, which are structurally rigid, cantilevered off the base of the lining. The fill does protect the walls from accidental impact. However, carrying the fill up to the top of the channel increases its height and consequently its width at ground level (by 2 to 3 feet). This can be a distinct disadvantage where cultivators are concerned at the loss of cultivated area. The alternative is to stop the fill at the base of the channel (a pathway being provided at that level), the channel then being free-standing. This is a common form of construction in some areas where width of right-of-way has to be minimised, but thickness of wall may be increased in view of the exposure of the wall to impact. This may put the cost of bricks at a disadvantage compared with other alternatives such as lightly reinforced half-round spun pipe or rectangular concrete flume, discussed later.

4. To summarize the rectangular brick lining can be an effective solution provided that:

- In embankment reaches, the embankment is very thoroughly compacted.

- Soils are not unduly expansive.

- Close supervision in brick-laying is assured.

- Width of right-of-way is not a critical item.

Trapezoidal Brick Linings

5. For larger channels (minors) the self-supporting vertical walled rectangular section becomes impractical structurally, and the trapezoidal section has to be adopted, the lining being supported by the lateral fill, or the excavation if in cut. This is also an option for smaller channels (watercourses) as an alternative to the rectangular section.

6. The lining may be of standard brick, or of thinner brick tiles (such as 2 x 6 x 12 inches) specially made for the purpose. For large canals double brick or double brick-tile linings may be used, but these are outside the range of the present discussion.

7. As the lining of the sides is resting on fill in embankment reaches, it is particularly sensitive to settlement. Even uniform settlement will cause cracking at the junction between base and sides. Non-uniform settlement will cause more general cracking, particularly parallel with the canal and at about half-height of the lining. Standard bricks in mortar are rigid and cannot accommodate differential soil movement. Cracking causes seepage which may lead to erosion of material from behind the lining and subsequent collapse, or plant-growth and development of root-pressure behind

the lining. A solution is to use plastic sheet behind the lining. This will not stop cracking, but it will stop leakage and further deterioration. The plastic sheet becomes the primary barrier (discussed later). In circumstances where settlement or soil movement are unlikely to occur to significant extent (as in the sand soils of the Rajasthan Canal area) plastic sheet may be unnecessary.

8. As discussed previously, width of embankment and right-of-way are factors in channel design. With trapezoidal channels the embankment must necessarily be carried up to the top of the lining (higher, in the case of larger canals). The only design variables available are the width of shoulder or foot-way at the top of the embankment and the slope of the embankment fill. There is an incentive to make the latter as steep as possible. However, the embankment supports the lining in the case of trapezoidal channels, and it must be protected against erosion, particularly if steep slopes are used. Wind erosion of embankments can be a cause of failure of channel linings in arid dune-sand areas.

9. Summarizing, regular brick or brick-tile linings may be used in trapezoidal canals or watercourses, but their rigidity makes them particularly prone to cracking due to settlement (more so than rectangular brick linings, due to the sides of trapezoidal lining being supported by the fill). Use of plastic sheet, behind the brick lining, as the primary barrier, can prevent seepage through cracks and further deterioration of the lining.

Stone-Slab Linings

10. The attractions of stone-slab as a lining material are its strength, impermeability, and relatively low cost. Its disadvantages are the difficulty of making durable joints, and the associated problem of theft of slabs. Thicker slabs (40 to 50 mm) present less difficulty with joints than thinner material. In this discussion slabs of 20 to 30 mm thickness are referred to.

11. The simplest traditional practice is to form the joints with 5 to 10 mm of mortar "pointing". Any slight subsidence, or simply temperature changes, generally cause fine hair-cracks to appear in the pointing, with time, at a proportion of joints. Seepage begins, and vegetative growth within and behind the joint. Root pressure is likely to cause outward displacement of one slab with respect to its neighbour. Removal and theft of slabs is relatively easy, as the squared edge of the slab offers no resistance to outward displacement once a hair-crack appears. One means of overcoming the latter problem is the use of a steel retaining clip, locking adjacent slabs together, as shown on Plate 8.

12. The use of plastic sheet in conjunction with stone-slab linings is discussed later.

Concrete-Lined Channels

13. Forming in place is a common practice for concrete lining of larger canals, but not generally for smaller channels due to the difficulty of maintaining quality control in the field conditions under which most small channels are constructed. (Theft of cement and inadequate curing are particular problems.) Pre-cast integral lining units for watercourses, and

pre-cast slabs for watercourses and larger channels, are generally favoured as these are produced in central casting yards where supervision is simpler and the product is subject to acceptance testing.

14. The integral unit comprises a short length of the full cross-section of the lining. Although the term "lining" is generally applied, integral units may be used either free-standing (as flumes) or with back-fill. Methods of production currently employed include the following:

a) Casting in forms, using conventional wet-mix concrete. The forms are stripped after 12 to 24 hours.

b) Spin-casting of half-round units, two at a time, in the same type of mould as is used for full-round pipe.

c) The extrusion process, using "dry-mix" concrete, the mould being withdrawn (extruded) from the cast unit immediately after casting. This is the same method as is used for production of hollow concrete building blocks.

15. The problem with the first method is the need for a large number of moulds if a substantial rate of production is to be achieved. The second method (spin casting) is effective, and a considerable quantity of half-round lightly-reinforced pre-cast lining is being used for watercourses. The reinforcement represents about one-half of the cost of the lining but is generally regarded as desirable, in part to prevent breakage in transport and handling. It is a high quality lining, but at the upper end of the cost range. The third method, extrusion, produces units 25 to 30 cm in length of any shape desired (trapezoidal, square, etc.). They are unreinforced. With a well-graded well-shaped aggregate both strength and low permeability can be achieved. With less favourable shape of aggregate (some crushed basalts) or deficiency in coarse sand, permeability is less satisfactory and plastering of the inside surface or the use of a polyethylene sheet behind the lining is desirable (although not generally practised) for impermeability and smoothness. Adhesion of plaster is good due to the rough surface texture produced with such aggregates.

16. A fourth method of production is drypack concrete with pneumatic vibratory tamping and immediate stripping of forms. This may be applied to the production of small integral units, slabs and other components for larger channels, pre-cast structures, and pipes.

17. A fifth, relatively new construction material now coming into use is fibre-glass reinforced concrete. This is similar in some respects to asbestos-cement concrete, but chopped fibre-glass is the reinforcing material rather than asbestos fibre. Its use includes production of trapezoidal linings or free-standing flumes, usually in lengths of 3-5 m. Wall thickness is around 8 mm. The material is placed by a gunite-type process, cement-sand mortar and chopped fibre-glass being sprayed together on to a mould. A particular feature of the process is the requirement that an alkali-resistant glass be employed to withstand the alkaline environment of the mortar. One such glass is based upon zirconium sand, which occurs in some areas including the south-west coast of India. As the glass accounts for around 5% only of the weight of the finished product, cost of transportation of the glass is not a major item. Pilot scale work on irrigation application (including in India) is planned.

Buried Pipe as an Alternative to Lined Open Channels

18. Use of buried pipe in place of open channel watercourses is being increasingly considered for special situations (high land values, very small holdings, dune sand areas). Spun concrete pipe is commonly employed. An alternative is the packer-head method of production. With the latter method dry-mix concrete is fed into a vertical cylindrical mould, and compacted against the inside surface of the mould by spring-loaded rotating rollers mounted on a "packer-head" which moves progressively upward through the length of the form. The system may be employed for either reinforced or plain pipe. It is used very widely in the U.S. and elsewhere (West Asia) as a lower-cost alternative to spun pipe. This method of production has been extensively used for pipe of 300 mm diameter and smaller for irrigation, and as collectors for tile drainage, using relatively simple equipment. However, PVC pipe is becoming increasingly competitive for this lower size range.

Joints in Concrete Slab Linings

19. For canals of around 50 litres/sec and above, and in some cases for smaller channels (watercourses), pre-cast slabs or tiles are commonly used. The weak point in use of concrete slabs is the joint. Temperature variations and drying shrinkage eventually produce fine hair-cracks at a portion of joints, permitting seepage, lodging for seeds and plant roots, and eventual displacement of slabs by root growth or soil pressure. Use of a plastic sheet behind the lining can improve the situation and certainly lengthen the life of linings, but plant roots established in hair-cracks in joints of the slab lining may also eventually penetrate plastic sheet.

20. Whether or not such a sheet is used, the solution to the problem is a better joint, capable of remaining sealed even when slight movement due to shrinkage or other factors occurs at the joint, and also providing positive restraint (in shear), locking each slab against relative outward movement, against its neighbour. This prevents displacement of an individual slab by soil or root pressure. It also prevents removal and theft of slabs. A number of joint designs can provide these features. They are necessarily shaped interlocking joints, rather than square joints.

21. Production of slabs with well-formed shaped edges poses the choice referred to earlier, i.e. wet-mix with stripping of edge forms after a number of hours, or dry-mix and instant stripping of forms. (A fine-aggregate mix should preferably be used around the edges when filling the mould.) It is noted that the use of a hydraulic press (as in the production of square-edged tiles) cannot be used in the production of slabs with shaped edges. If dry-mix instant stripping is aimed at, mechanically assisted compaction must be used if volume production is to be achieved.

The Use of Plastic Sheet in Channel Lining

22. The materials commonly in use include low-density polyethylene (LDPE), high-density polyethylene (HDPE), and polyvynl chloride (PVC). Plastic sheet can be employed with soil cover only ("buried membrane" linings) for large canals in certain circumstances. However, for the smaller channels animal access and consequent damage to the plastic sheet would be a problem. Discussion here is confined to plastic sheet behind, and protected by rigid linings of brick, stone-slab, or concrete.

23. Current practices include the following:

a) Plastic sheet placed against tamped smooth soil (excavation or embankment fill), and brick, stone-slab, or pre-cast concrete slab, placed directly on the plastic sheet, with usual jointing.

b) Plastic sheet placed as above, and cement-sand plaster 10-20 mm in thickness placed upon it. The concrete or stone-slab is pressed into this plaster, while it is still soft and extrudes out into the space between slabs, forming the joint.

c) A thin layer of low-cement mortar is trowelled on to the soil (excavation of embankment) and allowed to set. The plastic sheet is placed upon it, followed by 10-15 mm cement-sand plaster and concrete or stone-slab as in b) above.

24. In case a), the plastic sheet is clearly intended as the primary water-retaining element, with the brick or slab lining giving physical protection. Placing the sheet directly on the tamped earth is satisfactory, particular care being taken that kankar nodules which could penetrate the sheet are not left exposed. A slurry of silty-clay may also be trowelled on to the surface for smoothness. The hydrostatic pressure on the plastic sheet, pressing it onto the tamped earth, is in any case very small with small channels, and penetration is not likely to be a problem either from the soil or from irregularities in the surface of the stone-slab. The thickness of sheet used in this application is commonly 100 microns (0.1 mm). Purchase price is approximately Rs2.5/m2. 1/ There is much to be said for using a thicker sheet, preferably not less than 200 microns. The purchase price of Rs5/m2 is still not more than 10% of the cost of the finished lining, and resistance to root penetration is considerably increased. With this type of composite lining, careful attention should still be given to jointing of slabs, not from considerations of leakage but to prevent lodgement of seeds and vegetative growth through joint cracks, which could eventually lead to root penetration. The sequence in construction of such a lining, using stone slab, is shown on Plate 9.

25. In cases b) and c), views differ as to the relative roles of the plastic sheet and of the 10-20 mm mortar layer. The mortar layer can be regarded as the primary water-barrier, with the plastic sheet simply preventing absorption of water from the mortar layer on placement, into the adjacent earth. That is a short term construction role, and could be provided by a very thin sheet. More generally, the plastic sheet is regarded as a back-up element, i.e. a secondary water-retaining barrier, the mortar layer being the primary barrier. The mortar layer may also be regarded as a means of ensuring good jointing, by extrusion, or as a means of giving added weight to slab linings. The mortar does not bind onto the plastic sheet, which is fortunate as otherwise shrinkage cracks between slabs, which penetrate the mortar layer, would also penetrate the plastic sheet by tearing.

1/ Indian Rupees, 1985: Rs11.80 = US$1.

26. Apparently satisfactory linings are being installed with all three of the methods described. It is suggested, however, that in view of the relatively low cost of the plastic sheet compared with the other elements in the lining, first emphasis should be on adequate thickness of sheet for durability, as the primary water-retaining barrier, and second on good quality jointing of the slab lining to provide permanent protection of the plastic sheet.

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PAPER C

IRRIGATION FROM SMALL TANKS

C. IRRIGATION FROM SMALL TANKS

C.1 BACKGROUND

C.1.1 The term "Tank" as used throughout India refers to a small reservoir commonly serving an irrigation area ranging in size from a few hectares up to 1,000 ha, occasionally larger. The term is used both for the reservoir itself, and also for the reservoir and irrigated area as a whole. The Tanks discussed in the following paper are in the range of 20 to 1,000 ha. They are within the size range classified as minor projects in India.

C.1.2 Historically, Tanks were the principal source of irrigation in much of India prior to the advent of large dams and major canal systems. They still account for a significant proportion of the total irrigated area in the central and southern states. Over large semi-arid areas not served by major canal systems, and with very limited groundwater potential, Tanks are in fact the only possible source of irrigation.

C.1.3 In view of its small size, a Tank and its irrigated area are commonly associated with a single village, and form an integral part of its socio-economic structure. It is this communal feature of Tank irrigation which distinguishes it from irrigation under medium and major projects, also the closer involvement of the beneficiaries in its operation.

C.1.4 Tank irrigation has recently attracted the attention of several international lending agencies operating in India, partly in view of the identification of Tanks with the small cultivator and partly because of the relatively short period of implementation of Tank schemes compared with larger irrigation projects. The first such venture of the World Bank, in association with Government of India, is the Karnataka Tank Irrigation Project, now under construction.

C.1.5 The purpose of this paper is to:

a) Review the main issues which arise in the design and operation of new Tank schemes. The discussion draws largely on the Karnataka experience but is also relevant to Tank development generally. It is intended for reference by those associated with project planning in State, Central Government and financing agencies.

b) Discuss the principal design questions, including the basis adopted in the Karnataka project. More detailed treatment of selected topics is given in the annexes.

C.2 TRADITIONAL TANK IRRIGATION

C.2.1 Most of the earlier Tanks in southern India were constructed for the purpose of paddy cultivation, supplementing rainfall in the wet season and, to the extent of water available, providing for a second crop of paddy in the dry. Limited cultivation of perennials (sugar-cane, bananas) often developed in the lower portion of the area, with supplemental dry-season irrigation from dug-wells or shallow tubewells supplied by seepage from the reservoir.

C.2.2 In semi-arid areas such as the central Deccan and northern Rajasthan, crops such as jowar, bajra, wheat and pulses are the staple diet, rather than rice, and these same crops are also grown under irrigation where water is available. In such circumstances delivery from the Tank is by contour canals extending down both sides of the valley. Distribution from outlets on these canals is by informal channel system constructed by cultivators. The contour canals are usually unlined, with few control structures other than the sluices at the reservoir. Delivery to the individual cultivator, particularly at the lower end of the system, is usually unpredictable and dependent upon demands of upstream users. Although irrigation in the semi-arid areas is primarily for non-paddy crops, there is usually a local area of wet-land immediately downstream from the dam, where seepage ensures sufficient water for perennials or in some cases a small area of paddy.

C.3 OBJECTIVES IN DEVELOPMENT OF NEW TANK SYSTEMS

C.3.1 In considering the case for undertaking a new programme of Tank construction questions to be answered include the following:

a) How effective are the traditional Tank systems?

b) Are there reasons for change in the design or operation of Tanks. Are there opportunities for improvement?

c) What should be the objectives, and the physical and economic criteria in the design of new Tanks.

C.3.2 Answers to the above questions depend to a considerable degree upon the climatic and economic situation in the area under consideration. At one end of the scale is the area with abundant monsoon rainfall and opportunity for coverage of a considerable proportion of the area with supply from Tanks in the dry season. The area is almost exclusively under paddy (rainfed or with supplemental irrigation) during the monsoon, and paddy is also the choice of most cultivators in the dry season, given a supply of water, and is likely to remain so. In this situation the traditional system with purely field-to-field distribution is reasonably efficient and the opportunities for improvement (through introduction of a formal distribution system) are marginal, particularly with small Tanks. At the other end of the scale is a semi-arid region with potential for Tank development limited (because of the low runoff) to a small proportion only of the arable area. The region depends for subsistence upon rainfed cultivation of jowar, bajra, oil-seeds, etc., in the monsoon season, and will continue to do so. A Tank in this situation may be used for supplemental irrigation of those crops in the monsoon season, and of similar crops plus possibly wheat in the dry season. However, as the total contribution of irrigation to production of such staple crops in the area as a whole will be proportionally small, the Tank may alternatively be used, at least in part, for production of specialty cash crops (discussed later).

C.3.3 In such semi-arid conditions efficiency of water distribution is of particular importance. Here, there is considerable opportunity for improvement on the traditional system.

C.3.4 The more general situation lies between the two discussed. A Tank constructed 50 years ago, in such an area, may well have been designed purely for paddy production, and may still be devoted to paddy. However, this does not imply that a Tank being constructed today in the same area should be largely confined to that crop. Circumstances will have changed in the interim, including a considerable increase in population in the village concerned. Production of basic food requirements for the village is still of importance, but even this must be looked at in the context of both the rainfed and the irrigated lands available to the village, and with due regard to the need for cash income and agricultural employment in the area. Self-sufficiency in basic food crops at the individual village level ceases to be of primary significance with modern transportation, particularly if there is opportunity for alternative high-value irrigated cash crops and facilities exist for their transport and marketing.

C.3.5 The question of cropping patterns and provision for possible future changes in cropping patterns is discussed later in this note. For the moment it is sufficient to emphasize that capability of efficient distribution to non-paddy crops is likely to be a more important criterion in Tank design today than previously and is the principal area for improvement over traditional systems.

C.4 QUESTIONS OF DEVELOPMENT POLICY INFLUENCING TANK SYSTEM DESIGN

C.4.1 The questions relate to the type of crops proposed to be grown, the degree of flexibility to be provided for in regard to cropping pattern and water utilization, and particularly the irrigated crop intensity proposed, i.e. the extent of the area to benefit from a particular Tank scheme.

Crops to be Grown and Area to be Irrigated

C.4.2 The crops grown in an irrigated area are influenced by physical factors such as climate and soils and also by cultivator preferences and financial returns to the cultivator. Official recommendations reflecting Government priorities for food production may also influence choice of crops initially, but are difficult to enforce if they run counter to cultivators' interests.

C.4.3 Choice of crops centres around the question of paddy or non-paddy in wet and in dry seasons, the extent to which perennials may be grown, and the degree to which operation of the system will cater to the water needs of specialty crops including fruits and vegetables.

C.4.4 Decision is not required on all of these questions at the time of project design, except possibly the question of paddy. This is related to the more fundamental question of the extent of the area which will be served by a particular project, in effect the depth of water to be provided annually assuming uniform distribution over the service area. In current practice in India this may be as little as 40 cm (at canal head), or more than 1 m.

C.4.5 The procedure traditionally followed in project design is first to assume a particular cropping pattern, which involves decision as to both:

a) The relative proportions of areas under each of the irrigated crops (the crop mix); and

b) The percentage of the service area which is to be under irrigation in a season, or the total for the year (the seasonal or annual irrigation intensity).

The cropping pattern combines both (a) and (b), i.e. the annual depth of water application. This, related back to the quantity of water available annually, determines the size of the area which can be supplied.

C.4.6 This traditional procedure, deriving the size of the command area from an assumed cropping pattern, perhaps obscures the fact that the irrigation intensity to be adopted is a socio-economic question, not an agronomic or technical one. The same volume of water that can be utilized on 100 ha with 150% annual irrigation intensity could instead be used on 200 ha with 75% annual irrigation intensity, the crop mix being the same in either case. The depth of water applied annually to the area as a whole would be half in the latter case compared with the former. The reason for possibly serving 200 ha rather than 100 ha would be purely a sociological one, i.e. spreading the benefits of the resource over a larger number of beneficiaries, which can be a very pointed question in a semi-arid area. Size of service area is a basic decision in project design, whereas crop mix is not. The latter may vary considerably in future years, from the initial design assumption.

C.4.7 With regard to paddy and perennials it is obvious that with a fixed amount of water available, a crop mix with a high proportion of dry-season paddy or perennials and a high irrigation intensity will lead to a smaller service area than if paddy or perennials are excluded. An area which for local reasons, is likely to be a predominantly paddy area should therefore be designed accordingly, and possibly with 100% wet-seasonal irrigation intensity. In the more general case, however, paddy may be regarded as a cultivator option for the use of his allocated amount of water, but on the understanding that he will receive no more water per hectare than his neighbour who grows non-paddy crops, and consequently that the proportion of his holding under paddy will necessarily be small. The same philosophy may be applied to perennials. In mixed-cropping the question tends to resolve itself, with paddy being confined to local low-lying wet areas where irrigation requirements are in any case relatively modest.

C.4.8 To summarize, two basic policy decisions in the design of a Tank system are:

a) Primarily paddy or not.

b) In the latter case the extent of the area to be served by the available water, i.e. the annual irrigated crop intensity or simply the annual depth of irrigation to be made available.

Economic Criteria in Project Evaluation

C.4.9 The social and economic benefits of a small Tank scheme on the adjacent village area, particularly in a semi-arid environment, go well beyond the assessable market value of the basic crops produced. The Tank becomes, in effect, a part of the village infrastructure. While evaluation of indirect benefits has always presented a problem in irrigation, and is not generally attempted with larger projects, such benefits cannot be ignored in the case of Tank irrigation. The small size of Tanks implies relatively big cost of structures (dams, spillways) per unit of area served, but benefits in the broader sense can more than offset costs, provided that all such benefits are taken into account in project evaluation. Failure to do so can result in rejection of schemes in most deserving areas. On the other hand public funds are involved and there are limits to acceptable expenditure in relation to the extent of area developed and the numbers of population benefitted.

C.4.10 This issue has not been faced up to yet, in planning of Tank development. In the case of the Karnataka project the World Bank has established values for the net benefit which could be derived from a cubic metre of water, based upon model cropping patterns and irrigated crop intensity, for typical ecological situations. Capitalized to give the equivalent value of a cubic metre annually, in perpetuity, this provides a very convenient indicator of the upper limit of acceptable capital costs. (Refer to Annex C1 for details.) This simplified procedure has considerable merit, but it is nevertheless based upon conventional evaluation of conventional crops. In the Bank analysis no mention is made of upper limits to cost per hectare of service area, nor of acceptable lower limits or irrigated crop intensity. The figures derived for value per cubic metre of water are based upon models which assume certain cropping patterns and irrigation intensities, but otherwise the criteria established are silent on this subject. Value of production per cubic metre is largely independent of irrigation intensity. However, if a broader view is to be taken in the evaluation of benefits from a Tank scheme, particularly questions of justification for low intensity irrigation over a relatively large area versus high intensity over a smaller area, then criteria for minimum acceptable irrigation intensity, or maximum cost per hectare served, may also have to be considered.

Operation and Maintenance of Tank Schemes - Extent of Involvement of Government Agencies and Cultivators

C.4.11 The degree of responsibility taken by cultivator groups in the management of Tanks obviously varies with size of command. In the case of a small Tank irrigating some 20 or 30 ha it is apparent that Government agency can be expected to provide little more than periodic inspection, resolution of disputes where these arise, and possibly participation in pre-seasonal planning of water release. On the other hand with a Tank serving 1,000 ha, operation of at least the sluice-gates controlling releases from the reservoir is likely to be a Departmental responsibility, also operation of any control structures on the main canals. Practice in some States is to further extend Departmental operation, or supervision, down to operation of outlets from the main canal.

C.4.12 The extent of Departmental involvement proposed can have a considerable influence on project design, particularly the type of controls to be built into the delivery system. If they are to be operated and maintained largely by the cultivators themselves only the most basic controls should be provided.

C.4.13 Field channels or watercourses (below the outlets from the main canal) are generally operated by the cultivators which they serve, or their nominee, unless an unusual degree of Departmental control is provided. Maintenance of the channels and their structures (distribution boxes, drops, checks, turnouts and the channel itself) is also usually regarded as the responsibility of the cultivators. However, while maintenance of unlined channels does not present a problem, repair of masonry or concrete structures or channel linings requires use of materials not readily available to cultivators. The problem can be minimized by using only the most simple, robust, structures. A certain amount of maintenance is nevertheless required, and there remains the question of how it should be carried out, whether Departmentally or by cultivators with Departmental assistance. The latter course is preferable, as it reinforces the concept of communal ownership and responsibility for the channels. The problem is a real one, as deterioration of the field channel system can defeat any attempts to improve the efficiency of Tank irrigation. Before undertaking a major Tank construction programme aiming at an improved level of effectiveness in water distribution, the question of Departmental support in subsequent operation and maintenance should be seriously considered at Government level.

C.5 INTRODUCTION

C.5.1 In the following notes technical features of the design of Tank schemes are briefly discussed. More detailed treatment of selected topics is given in the annexes. Where there are optional approaches to certain design questions the available alternatives are discussed, as the paper is intended for general reference. However, the particular practices adopted in the case of the Karnataka project are specifically noted.

C.5.2 The following topics are discussed:

- Yield Hydrology.
- Determination of Capacity of Reservoir.
- Cropping Patterns and Crop Water Requirements. Irrigation Intensity and Size of Service Area.
- Determination of Capacity of Main Canal.
- Design of the Conveyance System.
- Design of Distribution System Within the Outlet Command.
- Hydraulic and Structural Designs.
- Operation of Tank Schemes.
- Sedimentation and Catchment Protection.

C.6 YIELD HYDROLOGY

C.6.1 Because of the small size of the streams involved and often their remote location, river-flow records at or near Tank sites are rarely available at the time of project design. Reliance consequently has to be placed on estimates of runoff based upon rainfall records. However as rainfall on small catchments in semi-arid areas is extremely variable from year to year, with wide differences between adjacent stations in the same year, derivation of a series of historic monthly rainfall figures for a project catchment is at best an approximation. Considering also the uncertainty in prediction of runoff from estimated rainfall, it is apparent that the series of annual yields at the reservoir site derived for design purposes is also quite approximate.

C.6.2 A method of estimation of runoff currently used in India is that due to Strange, who published (in 1895) coefficients relating total monsoon season runoff to total seasonal precipitation. Catchments are classified with regard to runoff characteristics (topography, soils, vegetative cover, etc.) as good, average or bad. As the latter are value judgements, and as the basic coefficients are approximations in any case, the net result is an accuracy of forecast probably of the order of plus or minus 20%. This level of uncertainty should be kept in mind in project design, and in planning of system operation. It is also emphasized that stream gauging should be initiated as soon as field investigation staff move on to a Tank site, so that estimates of runoff may be checked against actual data as early as possible.

C.6.3 A further check on yield estimates may also be available from existing Tanks in similar adjacent areas, particlarly by inference from the record of the end-of-monsoon storage in a reservoir over a number of years.

C.6.4 Strange's coefficients relate total monsoon season runoff to rainfall, and do not indicate monthly distribution of yield during the season. It is apparent that runoff from a particular rainstorm falling on the relatively dry catchment early in the monsoon would be less than from the same storm falling upon the near-saturated catchment later in the season. However, any attempt to quantify this effect is necessarily approximate. The procedure adopted in the Karnataka project, based upon further work of Strange relating runoff from an individual storm to the state of saturation of the catchment (dry, moist, or wet), is outlined in Annex C2. It is again emphasized that the method of estimation gives indicative values only. Actual month by month monsoon-season yields from a small catchment in semi-arid conditions is likely to be highly variable. Operation of the reservoir and canal system should be designed with this in view.

C.7 DETERMINATION OF CAPACITY OF RESERVOIR

C.7.1 Several factors are involved in determination of the desirable reservoir capacity, not the least of which is the relative cost of storage at the particular site. These include the following:

a) The estimated monsoon season yield from the catchment.

b) The amount of the monsoon yield which it is proposed to use for irrigation in that season, and the amount proposed to be stored for use in the following dry months.

c) The size of area available for irrigation, i.e. the potential demand for water in wet and dry seasons.

d) The topography of the reservoir basin and of damsite, also geologic conditions at the site, which together influence the cost of storage per cubic metre as a function of height of dam (or total storage capacity). Costs include the spillway and spillway channel which (according to site conditions) may be significantly influenced by the adopted value of reservoir full supply level.

C.7.2 With regard to item (b) there are two main alternative uses for irrigation, either primarily for supplemental supply to wet season (kharif) crops, or primarily for dry-season (rabi) crops. A third alternative, carry-over for pre-monsoon or early monsoon irrigation in the following year, is also possible although rarely practised with small Tank schemes. The choice between the first two, or some intermediate course with limited kharif irrigation in critical conditions only, depends upon the relative returns from wet season and dry-season irrigation as perceived at the time of project design. However crop prices, cultivator preferences, and cropping practices can change with time. Reservoir capacity, once constructed, cannot. It is consequently desirable to take a reasonably long view in determining reservoir capacity. If storage can be made available at relatively favourable cost at the site in question it is reasonable to maximise storage capacity. Conversely at a relatively expensive site emphasis may have to be placed on monsoon season irrigation and less on storage for dry-season use, the ultimate situation being a run-of-river scheme with no storage, and irrigation in the monsoon season only.

C.7.3 In the Karnataka Tank irrigation schemes, net storage capacity provided ranges from 20% to 85% of the estimated "50% probable" annual yield from the catchment.

C.7.4 The most important variable is undoubtedly storage cost at the site. It is most desirable that an approximate curve of cost of storage capacity be prepared in each case, and comparison made between cost of an increment in storage capacity and the corresponding incremental volume of water stored each year (rather than being spilled) and its value. The procedure is discussed in Annex C3. It is not sufficient to establish the viability of a scheme based on a particular arbitrarily adopted value of net storage capacity. The relative merits of a greater or a lesser amount of storage capacity should be checked by simple approximate methods.

C.7.5 The above discussion illustrates one of the problems of design of Tank projects. A Tank scheme is in no way different from a larger irrigation project, in respect of the physical and cost factors to be considered in design. However, the small size of a typical Tank admittedly limits the amount of time which can be spent on its analysis, and there is a natural tendency to adopt the "rule-of-thumb" approach. A more satisfactory course is to check the main items in design (e.g. size of command, canal capacity, reservoir capacity, etc.) for each individual scheme on a logical basis, rather than relying upon "rule-of-thumb", but using more approximate methods of analysis than would be applied for a larger project.

C.8 CROPPING PATTERNS AND CROP WATER REQUIREMENT - IRRIGATION INTENSITY AND SIZE OF SERVICE AREA

C.8.1 As noted in Chapter C.1 the question of irrigation intensity, or the extent of command to be served by the available supply, is a socio-economic policy decision. However, it is not usually expressed in these terms, but rather through the adoption of an acceptable range of annual irrigation intensity (sum of kharif, rabi, and two-seasonals and perennials). In the Karnataka project the annual intensity planned is generally in the range 100% to 150%, with one-third of schemes at the lower figure. For comparison the annual irrigation intensity with the cropping patterns suggested in the World Bank appraisal report (for the semi-arid zone) ranged from 145% to 155%.

C.8.2 As cropping patterns and irrigation practices may change, two more basic indicators of intensity of water application are of interest. These are:

a) The total annual depth of water application assuming that the "50% probable" yield of water to the project, less reservoir evaporation and distribution losses, is spread uniformly over the command area (i.e. the equivalent total annual depth at the field over the whole command).

b) The possible depth of water application in the dry season assuming that the full reservoir live storage contents less distribution losses is spread uniformly over the command (i.e. the possible dry-season depth of irrigation at the field, calculated over the whole command).

C.8.3 With the cropping patterns and irrigation intensities suggested in the World Bank appraisal report (annual intensity 145 to 155%) the annual depth of water application at the field is between 620 and 770 mm.

C.8.4 In comparison, in those schemes in which the design annual irrigation intensity is 100%, the annual application ranges from 350 to 530 mm (of which dry-season application is in the range of 200 to 400 mm).

C.8.5 No particular significance is attached to the departure from the Bank typical cropping patterns, in the direction of spreading irrigation over a wider area of command. The lower irrigation intensity increases total canal cost, but the latter is a relatively small proportion of Tank scheme total costs. It also reduces capital cost per hectare, which as indicated in para C.4.9 can be relevant to the question of limiting the expenditure of public funds per hectare of beneficiary area. A low irrigation intensity does, however, introduce operational factors which must be considered in canal design.

C.8.6 Those Karnataka project schemes with nominal annual irrigation intensity of 100% probably represent a reasonable minimum design intensity for the semi-arid conditions of much of the project area. It is emphasized, however, that the nominal irrigation intensity is not a particularly specific indicator of intensity of water use, for the following reasons:

a) Although a design cropping pattern is usually prepared with some care, and with due regard to agro-climatic conditions in the particular area, the crops actually grown in subsequent years may differ considerably from those assumed.

b) Calculation of crop water requirements, an important step in determining irrigation intensity, is at best an approximate process (accepted methods of calculation give figures varying over a range of 20% from one other). Furthermore cultivator practice in dry areas is usually to apply considerably less water than the calculated optimum amount. Hence actual irrigation intensities are likely to be higher than the calculated design figures.

c) An important question in formulating the design cropping pattern is the relative importance of supplemental irrigation of wet season crops versus full irrigation of dry-season crops. Practices in existing Tanks vary, and are likely to vary further in the future. The seasonal amount of water required to supplement monsoon season rainfall is less, in most situations, than the amount required for irrigation of a crop in the dry season. Hence the area which may be irrigated, and the estimated annual intensity, depend very much on assumptions as to wet season versus dry-season irrigation.

C.8.7 The alternative parameters previously discussed, i.e. depth of water available at the field annually, and in the dry season (from storage), together give more specific indication of the amount of water to be supplied per unit of area than does the design irrigation intensity. It is suggested that if limits are to be established for the design of future Tank schemes they should be based upon depth of water available at the field annually rather than on annual irrigation intensity.

C.8.8 To put this discussion of cropping patterns and irrigation intensity in operational terms:

a) Particularly for light irrigation in semi-arid areas, a starting point in project design, and the basis for determination of area of command, should be a policy decision regarding the annual depth of irrigation to be applied (or the acceptable range).

b) A design cropping pattern (proportions of various crops and irrigation intensity) based upon available water supply, storage capacity, estimated crop water requirements, and the area of command derived in (a), should then be prepared.

c) The nominal design cropping pattern so obtained may be used for economic analysis (where more general methods such as value per cubic metre of water are not employed). Monthly or fortnightly peak water requirements (canal releases) should also be worked out for the nominal pattern, also a reservoir operating schedule.

d) <u>However</u>, it should be kept in view that the design cropping pattern is an arbitrary one, with no particular assurance of its being followed in the long term. In final determination of canal capacity and in studying canal operating procedures other possible crops and other assumptions as to wet season versus dry-season irrigation should also be considered.

C.8.9 Depth of water applied annually (or in the dry season) calculated over the area of command as a whole, has been used above as an indicator of water availability at the field. A typical figure for the cases discussed, assuming use of full reservoir capacity for dry-season irrigation, is 300 mm. It is emphasized that this does not infer the application, literally, of that depth of water over the whole area. A particular cultivator with 1 ha of land might well use his dry-season entitlement, calculated as 300 mm over 1 ha, as 600 mm over one-half hectare, the remainder remaining unirrigated for the season. Scheduling of deliveries in the main canal, in field channels, rotationally to the farm, and rotationally to individual fields, are discussed later.

C.9 DETERMINATION OF CAPACITY OF MAIN CANAL

C.9.1 The sequence in design followed so far is as follows:

a) Determine the available yield from the catchment.

b) Decide upon the capacity of the reservoir.

c) Decide upon the size of the command area.

C.9.2 The desirable capacity of main canal follows from these three factors and the proportion of the various types of crop to be grown in the monsoon and the dry seasons. As previously noted the term "cropping pattern" conveys both the crop proportions and also the intensity of irrigation, i.e. the percentage of the command area actually under irrigated crop. The latter depends upon the size of command and the amount of water available. Thus, having established the yield hydrology and decided upon the size of command, the proportionality between crops (crop mix) can be nominated. However, the irrigation intensity corresponding to that crop mix has to be derived from the other three factors, i.e. the "cropping pattern", which includes the factor of irrigation intensity, cannot be nominated if the size of command has already been determined, only the crop mix can be nominated. The converse process of nominating the cropping pattern and deriving the size of command may also be followed, but for reasons discussed earlier the course recommended for Tank projects is to decide upon the area to be commanded first, on general grounds of distribution of the water resource (with some regard to crops to be given). The irrigation intensity corresponding to any particular crop mix is then derived.

C.9.3 The simplest approach to this calculation is to consider a hypothetical 100 ha of command under the crop mix proposed and an assumed 100% peak season irrigation intensity. 1/ Annual, seasonal, and fortnightly irrigation requirements are then calculated for this 100 ha. Comparing the annual and seasonal requirements with the annual yield and the live storage available gives (simply by division) the number of hectares under that crop mix and 100% irrigation intensity which could be irrigated with the water and storage available. If, for instance, the answer is 300 ha but the command area already decided upon is 500 ha, the peak season irrigation intensity must be scaled down from 100% to 60%. This factor applied to each of the individual crops in the crop mix gives "the cropping pattern" (proportionality and percentage intensity) appropriate to the adopted values of size of command, yield, reservoir capacity, and the particular crop mix under consideration.

C.9.4 Required canal capacity for that crop mix also follows from the same calculation. The peak fortnightly requirement for the hypothetical 100 ha under 100% intensity, scaled up to the calculated 300 ha under 100% intensity (in this example), gives the actual peak fortnightly requirement. The fact that the actual command is to be 500 ha (or any other size) does not affect canal capacity, only length of canal. To reiterate, canal capacity required is governed by available water, reservoir capacity, and crop mix. It is not influenced by size of command or irrigation intensity. However if size of command is known and irrigation corresponding to that command and the crop mix in question has already been calculated, canal capacity can be determined by working backwards from crop mix and irrigation intensity (together "cropping pattern") and size of command. The capacity arrived at is the same in either case. This is important to note, as a common method of determination of canal capacity simply from a "water duty" per hectare follows, in effect, the second method.

C.9.5 The important variable in the above calculation is the proportion of the various irrigated crops. While there may be a nominated "design" cropping pattern, as discussed earlier, actual and future cropping patterns may depart radically from the original assumption. Canal capacity should consequently be checked against any likely variations from the nominal design cropping pattern, and capacity provided accordingly. If actual peak capacity required initially is less than that actually provided, this can readily be accommodated by reducing the period of supply in the canal rotational operation. The important consideration is not to limit future operation of the system by constraints of canal capacity.

1/ This may be either monsoon season or dry season, according to the crop mix in question.

C.9.6 The determination of canal capacity discussed above should be followed for larger Tanks, and for representative smaller schemes. Two short-cut approaches remain to be discussed, either for rapid approximate determination of canal capacity for smaller schemes, or as a quick check on canal capacity.

C.9.7 The first is the rule-of-thumb formula suggested in the Karnataka project appraisal report. It is as follows:

Capacity of canal at canal head (litres/sec) = (0.7 + 0.5 p) x area of command in hectares.

The factor "p" is the proportion of the command under paddy. The formula is based on a duty of 0.7 litres/sec/ha for crops other than paddy, and 1.2 litres/sec/ha for paddy. Comparing the figure of 0.7 litres/sec/ha with actual consumptive requirements in the peak rabi season month of March (ETo = 5.4 mm/day) and using the "project efficiency" of 70%, the canal-head requirement for 100% dry-season irrigation intensity would be $\frac{5.4}{0.7}$ or 7.7 mm/day, corresponding to 0.9 litres/sec/ha rather than the assumed 0.7. It is evident that a canal capacity based upon the latter would be capable of supplying $\frac{0.7}{0.9}$ or 78% of the command (assuming sufficient water were available), i.e. a dry-season irrigation intensity of about 80%. As it is not generally planned to exceed that figure, the canal capacity obtained by use of the formula should be adequate for dry-season needs.

C.9.8 The rapid approximate check on proposed canal capacity applies to schemes with a considerable proportion of dry-season cropping (generally the case in the Karnataka project), supplied from the reservoir. The maximum possible indicated value of dry-season capacity at canal-head is obtained by assuming that the reservoir is full at the beginning of the dry season and is empty at the end. A very simple approximate check on dry-season requirements under those circumstances is obtained by calculating the uniform continuous rate of discharge needed to empty the storage over the four or five months of dry-season cropping, and then applying a judgement factor of around 1.25 to allow for the peak requirement being greater than the average. It is noted that the figure so obtained is entirely independent of size of command, irrigation intensity, or efficiency of delivery. It is a valuable basic check. It is emphasized that the figure obtained represents the peak canal-head discharge required <u>if</u> the whole of the reservoir live storage is used in the dry season. The "design" cropping patterns may change in the future while canal capacity cannot. Furthermore the design cropping pattern is based upon a "50% probable" year. In wetter years a full reservoir at the end of the monsoon season will be encountered frequently. The capacity of the canal should be sufficient to permit effective use of the water then available.

C.9.9 It is emphasized that the nominal canal capacities determined in the above discussion assume <u>continuous</u> operation of the main canal in the peak season. As discussed in the next section this may not be the case, particularly with small Tanks where daylight-only operation is proposed. If the canal system is to operate only half of the time in the peak season then the nominal capacities determined above must be doubled.

C.10 DESIGN OF THE CONVEYANCE SYSTEM

C.10.1 There are four principal factors to be considered in the design of an irrigation canal system.

a) The anticipated peak rate of water demand for the command as a whole. This is the nominal canal capacity as discussed in the previous section.

b) Whether the rate of demand, or more specifically the rate of supply, will be uniform (per unit of area) over the whole command, or whether it may vary from one portion of the command to another.

c) Whether, in the period of peak demand, the whole system (main canal, distributaries, minors, outlets) will operate continuously or rotationally, i.e. week on/off, or 12 hr on/12 off for small systems.

d) How rates of supply less than the peak will be provided:

- By reduction of rates of flow throughout the system.
- By maintaining the same rate of flow as for peak demand, but reducing the days per week (or fortnight) of operation of the whole system, i.e. by rotational operation of the system as a whole.
- By reducing the rate of flow in the main canal and running it continuously, but rotating supply at full flow to minors or to outlets.

C.10.2 Answers to the above questions depend to a considerable extent on the size of the project. They are likely to be different for a 200 ha command compared with one of 20,000 ha for a number of reasons, including the following:

- While it is possible to rotate operation of the canals of a small system over a short time interval, with the much longer canals of a major system and the longer filling time, it is not.
- Rapid filling and emptying of a large lined canal is undesirable for structural reasons (hydraulic pressure behind the lining). With a small canal (typically less than 900 mm deep in a small Tank scheme) this is not a significant factor.
- In a large project Departmental operation of regulating structures on main canals is provided. In a very small project Departmental involvement is minimal, and simplicity of operation is of primary importance.

C.10.3 In the Karnataka Tank Irrigation Project design is based upon the following assumptions, or decisions, regarding the points raised above:

- The rate of supply will, in general, be uniform throughout the command of a particular scheme. Most of the outlet commands are sufficiently small that they extend from canal down to valley bottom. Differentiation in rate of supply may be practised within the outlet command (e.g. as between upper areas and lower) by cultivators, but the rate of supply per unit of area of outlet command as a whole is uniform throughout the scheme. In a few larger schemes where the width of command (from canal down to the river) is larger, it is commonly divided into two outlet commands, an upper and a lower, with separate outlets from the main canal, permitting separate scheduling of delivery should this later prove desirable. This, however, would be exceptional. The rate of delivery (litres/second/hectare) is uniform throughout a particular scheme.

- During the period of peak demand the whole system including "main canal", minors if any, and all outlets, operate continuously. Exception is made for schemes with small enough command for operation in daylight hours only to be practical (200 ha or less), in which case the whole system cycles on/off daily. There may be further exception for very small commands in which operation even in the period of peak demand is restricted to less than seven days per week (discussed later).

- During periods of less than peak demand or restricted availability of water), reduced rate of supply will generally be achieved by operating the whole system (canals and outlets) at full design capacity but for a restricted number of days per week or per fortnight. The exception will be the case of a relatively large scheme (750 to 1,000 ha or greater) with main canal 10 km or more in length, in which case the canal filling time (three or four hours in this case) is such that on/off operation with the period "on" less than about three days would be impractical. In that case in periods of severe restriction in supply, particularly if weekly rotational supply to the field has to be maintained, the main canal may be operated rotationally but also with reduced rate of flow. Outlets will still operate at full flow (possible 10-15% less) but rotationally (in groups) on the main canal. Where there are minor canals (exceptional in the Karnataka project), the minors will always operate rotationally at full flow on the main canal.

C.10.4 Adoption of the above criteria has led to a simple system in which under most circumstances (the exception noted above) the canal and all outlets operate together, with no adjustment or gate operation required at outlets, the only control being the opening and closing of the head-gate (sluice) at the reservoir.

C.11 DISTRIBUTION BELOW THE OUTLET FROM THE CANAL

Capacity of Outlet - The Delivery Stream

C.11.1 An irrigation system is made up of a branching network of successively smaller canals (main, branch, distributary, etc.) with canal capacity broadly proportional to the size of the area served, becoming progressively smaller with smaller command. In many of the older irrigation systems this proportionality continued down almost to the field, certainly to the farm boundary, the flow in the final channel being very small indeed. The flow in the whole system right down to the farm was continuous in the season of maximum demand.

C.11.2 Disadvantages of this type of operation include the very low efficiency of distribution of water on the field with such small flows (particularly for crops other than paddy), and the proportionally large seepage losses incurred with such small channels. Furthermore there is no way of ensuring equality of distribution, particularly between head-end and tail-end users, nor of determining or regulating the amount of water applied by any particular user. However this technically primitive, low efficiency, system had the one merit of requiring very little operational attention below the level of the minor canal.

C.11.3 Largely in the interests of improved field and distribution system efficiency, the concept of a desirable rate of delivery to the farm, the "delivery stream", has been introduced. This rate is generally considerably greater than the flow provided in the earlier systems. Supply at the farm consequently has to be made discontinuous, with neighbouring farms taking the flow in turn. Small and large farmers take water at the same rate during their respective turns, but for different periods of time.

C.11.4 The point in the total delivery/distribution system at which canal flow ceases to be proportional to area served by the canal, and is determined instead by consideration of minimum stream size for efficient field application, is the outlet from the minor canal.

C.11.5 Terminology used for the distribution system downstream from this point differs between States. The outlet itself is variously referred to as "the outlet", or as the "pipe" (as it is often formed by a pipe), or the "spout". The area which is serves is referred to as the "outlet command", or elsewhere as the "chak". Divisions within it are referred to in some States as "sub-chaks". In others the division itself is the "chak". In these notes the terms used will be "the outlet", the "outlet command", and "sub-areas" of the outlet command. Names used for the channel system within the outlet command also vary. In some States the channel is referred to as a "watercourse" down to the point at which it enters a sub-area of the outlet command (where division into sub-areas is employed) and thereafter it becomes a "field channel". In others it may be a "sub-minor" for part of its length. In Karnataka it is a "field channel" throughout.

C.11.6 The division of an outlet command into sub-areas (the "5 to 8 ha" areas) is an important concept in the design of distribution systems in major and medium projects (although less generally applicable to small Tank schemes as discussed later). Further, there is often a change from lined to unlined at the boundary of a sub-area, and also a change in jurisdiction (Departmental to communal) at this point. Consequently there is much to be said for making the distinction between the "watercourse" upstream of that point, and the "field channel" downstream of it. In order that the discussion may be more generally applicable the "watercourse" and "field channel" nomenclature will be used in these notes, with the understanding that for Karnataka Tanks the term "watercourse" may be taken as meaning the same as "field channel" (unless otherwise noted).

C.11.7 To summarize, the capacity of all channels below the outlet, whether classified as watercourses or field channels, is the same throughout the outlet command. Furthermore all points of delivery from the channel system to the farm (turnouts) have the same capacity as the channel, and each point in turn takes the whole flow in the channel. There is no further sub-division of flow below the outlet. This arrangement of one turnout at a time taking the whole flow in the watercourse/field channel system is now widely used in India because of the simplicity of control of rate of supply to the turnout. The outlet from the canal is the last point at which regulation of flow must be exercised. Thereafter, at branches and turnouts throughout the watercourse/field channel system flow is either "on" at full outlet capacity or "off". However, the system is not universally used elsewhere. For instance in the Chao Phrya irrigation area in central Thailand three turnouts may be in operation at one time, and in Sri Lanka two outlets, in effect moving the last point at which regulation of flow must be exercised (i.e. diversion of a part of the flow) downstream to the turnout.

C.11.8 The "minimum desirable rate of delivery" referred to earlier is not a fixed unique value. Factors which may influence it in any particular project situation include size of field, type of land preparation for irrigation, infiltration rate of soils, erodibility of soils, topography, size of farm (as affecting length of run of farm channel), experience of cultivators in water management, and size of the outlet command. To illustrate, the desirable delivery stream in the case of a relatively small compact outlet command with a high proportion of lining, serving small farms (with short runs of farm channel), could be considerably less than in the case of a larger command with a lesser proportion of lining, serving larger farms with long farm channels and large fields. The ultimate example of the former situation is a "watercourse" consisting entirely of buried pipe delivering at points close to the field. In this case a relatively small stream can be delivered efficiently.

C.11.9 The above discussion has centred on the minimum desirable delivery stream. There is also a maximum desirable rate of delivery although this is possibly less well defined. The maximum rate is influenced particularly by adequacy of land preparation for irrigation, risk of erosion in case of spill (notably on sloping lands), and the extent of experience of the cultivators in water management.

C.11.10 For Tanks schemes the delivery stream should generally be between 15 and 25 litres/sec, the lower figure applying to smaller outlet commands. This range is an important factor in achieving a satisfactory level of irrigation efficiency, and should not been lightly set aside for convenience in distribution system layout.

Size of Outlet Command

C.11.11 As discussed earlier, in the design of distribution system recommended for Tank schemes (and as practised in the Karnataka project) all minors and outlets operate together with the main canal, at least in the peak season. The total design capacity of all outlets has to equal the capacity of the main canal at canal-head. 1/ Put alternatively, the canal-

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1/ The effect of losses in the main canal between canal head and outlets is negligible for the small, short, canals of Tank projects, particularly where lined head duty in litres per second per hectare is the same as the duty of the outlet in the same units (for instance 1.0 litres/sec/ha for a system operating continuously in the peak season, or 2.0 litres/sec/ha for the same scheme if designed to operate 50% on/50% off in the peak).

C.11.12 The size of outlet command follows directly from the outlet duty and the size of the delivery stream. Thus if the duty is 1.0 litres/sec/ha and the delivery stream is 20 litres/sec then the size of outlet command which can be supplied by the delivery stream is 20 ha. If the duty is 2.0 litres/sec/ha (operation 50% on/50% off) the size of outlet command for a delivery stream of 20 litres/sec would be:

$$\frac{20}{2.0} \text{ or } 10 \text{ ha}$$

More generally, area of outlet command (ha):

$$\frac{\text{Delivery Stream (litres/sec)}}{\text{Duty (litres/sec/ha)}}$$

C.11.13 As the design duty is uniform throughout the command (in the systems discussed) the two variables are size of delivery stream and area of outlet. The larger the delivery stream the larger the area of the outlet command which may be served by it. In relatively straightforward topographic situations it may be possible to keep all outlet commands of the same area and all delivery streams of the same size, on a particular project. However in most small Tank commands, with irregular relatively steeply sloping topography, preserving uniform size of outlet command is difficult. The alternative courses are:

a) To vary the delivery stream in accordance with variation in size of outlet command (within the limits discussed earlier of around 15 to 25 litres/sec, with corresponding range of commands 15 to 25 ha in the case quoted above).

b) To keep the size of delivery stream uniform and to vary the duration of supply to each outlet in accordance with size of outlet command.

c) To keep the size of delivery stream uniform and to supply each outlet for the same period, and simply to accept the approximation that this implies (in effect giving an unduly large share of water per hectare to the smaller commands).

C.11.14 The solution adopted in the Karnataka system is (a), but limiting the range of sizes of delivery stream to four or five values between the limits of 15 litres/sec and 25 litres/sec. This system requires no operation of outlet gates under normal circumstances.

C.11.15 Solution (b) involves the operational problem of opening and closing outlets for various times, and making corresponding adjustments to flow in the supply canal. The latter problem can be avoided by "pairing" of small outlet commands. Thus two outlet commands each of half regular size can be operated sequentially, each for half the time, the flow in the supply canal remaining unchanged. However this still presents the problem of opening and closing gates at the paired outlets. The need for opening and closing of outlet gates in a situation with the low intensity of operational management anticipated in the Karnataka project is much to be avoided.

C.11.16 Solution (c) may pay a high price in water use efficiency and inequality of supply for the convenience of standardization of outlet capacity, unless the occurrence of smaller outlet commands is infrequent.

C.12 DESIGN OF DISTRIBUTION SYSTEM WITHIN THE OUTLET COMMAND

Basis of Design - Rotational Supply

C.12.1 There are two types of consideration in the design of the distribution system within the outlet command.

a) Operational, particularly simplification of organization of cultivators for rotational supply within the command.

b) Technical, including efficiency of conveyance, protection against channel erosion in sloping lands, minimizing right-of-way problems, and effective coordination of points of delivery with layout of farm channels and on-farm land shaping for irrigation.

C.12.2 In the topographic conditions of most major project commands (gently rolling, relatively flat, large areas) operational considerations predominate in distribution system design. In Tank schemes, however, particularly small Tanks in relatively irregular steeply sloping topography and small narrow commands, technical factors can assume greater significance.

C.12.3 Because recent developments in the design of distribution systems have been generated in major and medium projects the subject is discussed first with regard to such projects, and subsequently with regard to the particular problems of small Tank schemes.

C.12.4 As discussed earlier, delivery to the farm at a desirable rate for efficient field application (the "delivery stream") implies rotational delivery, each cultivator receiving the full flow for a relatively short period once in every rotational cycle. Such operation involves a considerable degree of discipline among the cultivators served by a watercourse, if illegal or out-of-turn diversion is to be avoided. Furthermore it is not always necessary, or convenient, for a cultivator to take water every time his turn comes due. He may wish to exchange turns with a neighbour. In areas of mixed cropping successful operation of the rotational system is indeed contingent on such cooperation. On the assumption that cooperation is more likely within small groups of neighbouring farmers than within a larger single group the concept has recently been advanced that the watercourse command should be divided into a number of sub-areas (e.g. 8 ha, or more recently 5 ha) to which primary rotational supply is given. There is a secondary rotation within each of the sub-areas. This arrangement leaves the basic position unchanged, i.e. each cultivator in the watercourse command receives, or is entitled to receive, the full delivery stream for a defined period of time in each rotational cycle. Dividing the outlet command into sub-areas has the following features:

- The channel from the head of the watercourse (the "outlet") down to the turnouts to the sub-areas may be regarded as virtually part of the irrigation system proper. It may also be constructed to higher standards (e.g. more lining) than the channels within the sub-area, and may be built and possibly maintained at Government expense, and probably on formally acquired right-of-way.

- Operation of the portion of the channel from outlet down to the turnouts to the sub-areas may be by Irrigation Department officer, or at least may come under closer Departmental supervision than operation within the sub-areas.

- The portion of the channel system within the sub-areas may be considered as communal property of the cultivators, and is likely to be operated and maintained by them.

C.12.5 The appraisal report for the Karnataka Tanks project referred to dividing the outlet command into 8 ha sub-units, but it also added two other technical criteria.

- The distance between any field and the nearest lined channel should not be greater than 300 m.

- In areas with permeable soils and/or slopes exceeding 2% this distance reduces to 100 m.

C.12.6 In fact the latter two criteria have proved to be more relevant than the 8 ha sub-area concept in the small Tank commands, in which the <u>whole</u> area of the outlet command can be as little as 10 ha (where the system is designed to operate in daylight hours only). Grouping of farmers into small organizational units is proposed, but not division into separable physical sub-areas each supplied by a single turnout in the classic pattern adopted for larger projects.

<u>Location of Outlets and Boundaries of Outlet Commands</u>

C.12.7 Design of the distribution system within the outlet command begins with selection of outlet locations and boundaries of the commands. In this operation there are usually many possible alternative arrangements and there is room for considerable judgement. A primary requirement is to obtain outlet commands within the desirable size range as previously determined. Location of boundaries involves consideration of other factors than simply size, but as a tool in layout it is convenient to prepare overlays of transparent (tracing) paper representing, to the same scale as the layout plan, typical areas within the size range aimed at, with shapes varying from elongated rectangular to square. These are simply an aid to judgement of area. The actual commands are likely to be quite irregular in shape.

C.12.8 The factors other than size referred to above are discussed in para B.4.19. In considering them it must be recognized that seldom can all nominal requirements be met in one outlet command. Some will often prove to be mutually exclusive. Layout of outlet commands is consequently a matter of compromise and judgement, with many possible solutions in most situations.

C.12.9 Location of the outlet itself is related to the boundaries of its associated command. Where the upper boundary of the command is the supply canal the outlet will generally be located at some point on the boundary. The actual location will be influenced by the canal profile, i.e. where it is in cut and where in fill. At the outlet it is preferable that the FSL of the canal should be at or above ground level. (In very flat topography FSL should be at least 30 cm above adjacent ground level, to avoid a long run of watercourse before fields can be commanded.) This requirement illustrates the conflict between simplicity of construction of the canal as a conveyance channel, and its other function as a supply channel for outlets. In a major or medium project these two functions are usually separated. The main and distributary canals are for conveyance only, and do not generally serve outlets. Only the minor is the supply channel, and its FSL should be kept high enough to give positive command. With a small Tank scheme, however, the primary canal, although still referred to as the "main" canal, is of the size of a minor in a larger project and functions both as conveyance and for supply to outlets. In this sense most outlets are "direct" outlets. For simplicity of construction, particularly avoidance of the canal being partly in fill where the fill material is difficult to compact satisfactorily (i.e. black cotton soils), it would be preferable to have the waterway fully in cut. On the other hand for most effective supply to outlets the FSL at the location of the outlet should preferably be at or above ground level.

C.12.10 Returning to the location of the outlet command itself, in larger Tanks with width of command (canal to river) a kilometre or more there may be upper and lower outlet commands, the former bounding upon the supply canal, and the latter served by a watercourse with a conveyance portion traversing an upper command before reaching the lower command and commencing to supply turnouts. This conveyance portion strictly speaking should be classified as a sub-minor and regarded (and constructed) as part of the canal system proper.

Surveys

C.12.11 Development of a Tank scheme for irrigation, as now conceived, includes design of the distribution system right down to the farm boundary. Furthermore location of the point of delivery to the farm involves some consideration being given to the method of water distribution which the cultivator is likely to adopt on the farm itself. These requirements underline the need for detailed topographical survey and updating the record of property boundaries on Revenue Department (Village) maps. The desirable scale of mapping for detailed layout is 16 inches to 1 mile or 1:4,000, which is commonly the scale of the Village cadastral plans. A contour interval of 1 ft or 0.3 m is desirable for the purpose and is as close an interval as the accuracy of surveying is likely to justify.

C.12.12 Such a detailed survey is not generally available, and is not essential, at the time of initial investigation of a prospective scheme. At that early stage a scale of 1:8,000 and a contour interval of 1.0 m is adequate except for very flat commands. The problem usually encountered is the level of accuracy of the later more detailed survey. Such surveying is apparently a tedious and unwelcome task, particularly in an area still without established camp facilities, and the results are often of very doubtful accuracy. However, for planning of outlet commands and initial alignment of watercourses/field channels, a 1:4,000 (or similar) scale plan with 0.3 m contours showing also roads, rivers, natural drainage features, and updated property boundaries, is essential. Subsequent layout and construction of watercourses/field channels will need actual field levelling of alignments and field check that areas to be served are in fact commanded by the planned turnouts. Land shaping (within the farm boundaries as later discussed) will also require actual field levelling, although the 1:4,000 contour plan should be sufficiently accurate for planning of land development.

C.12.13 Regarding methods of topographic surveying for Tank schemes, it is unfortunate that their small size and scattered location generally rules out stereographic air-photo contouring, probably also rectified or ortho-photo prints for use as a planimetric base for ground levelling. The remaining methods of survey are the following:

a) The traditional grid or "block" levelling, levels being taken at corners of an arbitrary rectangular grid.

b) Use of the 1:4,000 village map as the base for plotting, and taking levels of identifiable boundaries of "survey numbers".

c) Using plane-table methods preferably in conjunction with the 1:4,000 village map. The use of a self-reducing tacheometer to measure distances in association with plane-tabling is very effective.

C.12.14 The most appropriate method will depend upon local conditions. For instance, if an area is already levelled and bunded for paddy and the paddies are identifiable on the village map, it is necessary only to take levels at the corners of each paddy (similar to method (b)). As noted earlier, the problem with topographic surveys is the quality of the work. Close supervision and frequent checking are necessary.

Land Shaping for Irrigation 1/

C.12.15 A particular question is whether land shaping (levelling) will change the topography sufficiently to make it necessary to design the land shaping system and the watercourse/field channel system jointly. This question is of real significance only when land consolidation is proposed and/or a major levelling operation using heavy mechanical equipment. Land consolidation is very unlikely to be carried out in conjunction with small Tank development, however, largely for reasons of irregular topography and widely varying soil depth. For the same reasons the use of heavy equipment in land shaping is likely to be the exception rather than the rule in land development for irrigation in Tank commands. In general land preparation will be carried out with small equipment, usually by the cultivator himself, and certainly within the boundaries of the individual farm. In these circumstances subsequent land shaping should not interfere with already-constructed watercourses or field channels. Their design and construction can proceed ahead of land shaping, provided that the point or points of delivery to the farm boundary are checked with the cultivator to ensure compatibility with his farm development plans.

1/ See also paras B.6.1-B.6.6.

Layout of Watercourses/Field Channels

C.12.16 As the command areas of Tank schemes frequently have portions of their area in slopes of 3% to 5% or greater, and often in highly erodible soils, the safe efficient conveyance of water from the canal outlet down to the individual farm, and thence to the individual field is of primary importance. The Karnataka Tanks appraisal report expresses this by specifying that no field should be more than 300 m from a lined channel, or 100 m in slopes of more than 2% or in "sandy permeable" soils. This 2% provision very often prevails, and in fact erodibility, both in granular soils and in some types of highly erodible clays, can be a more pressing problem than permeability.

C.12.17 The appraisal report also requires the Irrigation Department to design and construct channels down to the individual holding, or to 1 ha if the holding is smaller. The report implies a distinction between the channel down to the "8 ha" block and the field channel within the block. However, as discussed earlier, with the small irregular outlet commands of Tank schemes, division of the command into such physical sub-units is not usually practical (although cultivators in the outlet command may still be organized into sub-groups for purposes of scheduling rotational supply).

C.12.18 The distribution system within the outlet command must be capable of delivering the whole flow from the outlet (the delivery stream) to each of the farm turnouts. The structures required are turnouts, drops or check/drops, crossings (for access by bullock-cart), control structures at branches, and the lining itself. These are described in para C.13.24. The specified maximum lengths of run in unlined channel previously noted (300 m/100 m), imply that the upstream portion of main stem of the distribution system will be fully lined, and frequently a part of the remainder. In steeply graded down-slope runs there is a choice between the following:

i) A lined channel laid on a grade of around 1%, running at sub-critical velocity, with drop structures at intervals.

ii) A lined channel on a steeper slope (a chute) with flow at above critical velocity, without drop structures.

iii) A lined channel on a steeper slope but with small (2 or 3 cm high) sills at frequent spacing (40 to 50 cm) forming a cascade, flow being at sub-critical velocity.

iv) In steeper slopes, a buried PVC pipe, flowing part-full and functioning as a chute (in reaches between outlet boxes).

C.12.19 No particular recommendations regarding selection of alternatives are made here. Relative costs of drop structures and of lining affect the choice. Flow at or above critical velocity requires a good quality lining (particularly the joints). A cascade may be a satisfactory solution. Buried pipe has considerable merit for steep slopes, particularly where traversing one outlet command en route to a lower command, provided that soil depth is sufficient (about 80 cm) to provide cover over the pipe. Velocities of 2 to 3 m/sec are acceptable with such pipe. Plate 4 illustrates a situation in which slopes of 5 to 10% have to be traversed. The plate also illustrates the fact that holdings frequently are long and relatively narrow down-slope strips. Cultivators can usually handle slopes of 2 or 3% in unlined farm channels by using cobbles or brush-wood to check erosion, but steeper slopes present a problem, particularly in long runs. It is therefore desirable to utilize the formal lined watercourse or field channel for down-slope runs to the maximum extent, as it is fully protected against erosion, and to locate farm turnouts so that farm channels will either run horizontally or for short runs only down-slope. The specification of not more than 100 m between field and lined channel will frequently require more than one turnout for a holding as illustrated on Plate 4 where a holding is 200 m in length, down a 4% slope. The lined field channel runs down the boundary of the holding and has turnouts to it both at the upper end of the holding and half way down its length. The last two turnouts are alternative points of supply to the farm, and are not used simultaneously. The technical advantage of maximizing the use of the lined watercourse/holding, where needed, outweighs the operational simplicity of one turnout per holding.

Layout of Distribution System for Very Small Tanks

C.12.20 The simplest outlet commands from the viewpoint of distribution system layout are those which are near-square in shape, or rectangular with the larger dimension running down-slope. In small Tanks, however, and in the upper portions of many larger Tanks, the width of the irrigated area immediately downstream from the reservoir is often as little as 200 to 300 m, becoming broader downstream. The most upstream outlet command is consequently long and narrow, running between the water canal and the river (Plate 2).

C.12.21 To illustrate, take the case of a small Tank designed for non-paddy crops (and operation in daylight hours only). Canal duty with such operation is 1.6 litres/sec/ha. The design delivery stream is between 15 litres/sec and 20 litres/sec. The equivalent range of size of outlet command is between:

$$\frac{15}{1.6} \text{ and } \frac{20}{1.6} \text{ or } 9.5 \text{ to } 12.5 \text{ ha}$$

For the moment assume 12.5 ha (para C.12.26, table, case (a)). If the average width of the left (or right) bank command adjacent to the reservoir is 150 m, then its length in the downstream direction is approximately 800 m. Down-slope gradient is assumed to be some 3% to 5% (commonly the case at the upper end of a command). From the cultivator viewpoint the most convenient arrangement would be the supply of water at a number of points along the length of the canal, such that supply from each was by down-slope farm channel, with relatively short horizontal runs. However, only one outlet can be provided from the main canal, per outlet command, if the very great operational convenience of having all outlets operating together (without the need for opening and closing of outlets) is to be preserved; cultivators cannot be permitted to take individual supply directly from the main canal. The solution in this case is to run a lined watercourse/field channel parallel with the main canal supplied by a single outlet, but with as many gated turnouts as are required for convenient rotational distribution to farm channels (Plate 2). Constructing a lined watercourse/channel parallel to a lined main canal on side-slopes of 5% could present a problem if trapezoidal sections were used, and could take up an appreciable part of the width of the command at this point. A more convenient solution is to use a flume type of construction for the main canal and the watercourse, in effect combining the two structurally, as also shown on Plate 2. The flume is economic for construction of a lined main canal on such side-slopes, if the capacity of the canal is about 600 litres/sec or less. This is particularly true if the alignment encounters hard rock, which is often the case near the damsite.

For structural convenience it is preferable for the watercourse to maintain the same grade as the parent canal, the outlet being at the upper end of the watercourse.

C.12.22 The arrangement shown (Plate 2) with a single outlet to the watercourse and six turnouts to the outlet command could be substituted (hydraulically) by eight direct outlets on the main canal, serving the same area. However, unless operated strictly in rotation, the latter arrangement would make it physically possible to divert 8 x 20 or 160 litres/sec to the 12.5 ha outlet command, with corresponding deficiency in supply to other outlets further downstream. The arrangement shown permits only 20 litres/sec to be supplied to the outlet command, and any mis-management of the turnouts on the watercourse concerns only the sharing of the 20 litres/sec between their cultivators within the 12.5 ha outlet command.

C.12.23 The topographic situation described above can be encountered also in some larger Tanks, although the width of the command is usually wider (200 to 250 m). However, a larger scheme is usually designed to run continuously in the peak season, as it is not possible to operate a long canal in daylight hours only. The duty is then 0.8 litres/sec/ha rather than 1.6, and the area of outlet command corresponding to a delivery stream of 20 litres/sec becomes $\frac{20}{0.8}$ or 25 ha (para C.12.26, table, Case (b)).

If the average width of the most upstream outlet command (left or right bank) is assumed to be 300 m its length becomes 830 m. This again is best accommodated by a lined watercourse parallel to the main canal with as many turnouts as is convenient for down-slope distribution within the outlet command. The structural arrangement shown on Plate 2 may also be the convenient solution, at least for the upstream narrower portion of the area.

C.12.24 The third case considered is the very small Tank, with command typically 50 ha or less. If one half of this area is on either side of the stream the area to be commanded per side, is less than 25 ha, with a canal length of around 1 km. If the design duty is the same as that previously considered, for supply in daylight hours only seven days per week, the desirable area of outlet command is some 12.5 ha requiring two outlet commands. In this case the upstream half of the canal would have a parallel watercourse, and the downstream half would be simply a watercourse.

C.12.25 For very small commands an alternative to the parallel lined watercourse is available. The area and the upstream/downstream length of the outlet command may be reduced sufficiently that the contour watercourse is no longer necessary. This reduction in size of outlet command can be achieved, without reducing the size of the delivery stream, by reducing the number of days per week which the canal system operates in the peak season (para C.12.26, table, Case (c)). This is done at the expense of increasing canal duty (and correspondingly the capacity) of the main canal. However, with canals of capacity up to 80 litres/sec this increase can be provided at proportionally small cost, most of which is offset by the omission of the parallel watercourse.

C.12.26 The three cases discussed are summarized in the following table:

Case	Operating hr/day	Operating hr/week	Canal Duty litres/sec/ha	Area of Outlet Command for 20 litres/sec
(a) Small Tank	12	2	1.6	12.5 ha
(b) Larger Tank	24	7	0.8	25.0 ha
(c) Very Small Tank	12	3	3.7	5.4 ha

Drainage

C.12.27 While surface and sub-surface drainage are often major factors in the design of large irrigation projects, particularly in flat terrain, the topography of most Tank schemes ensures rapid runoff and drainage works required are usually minimal. Conveyance of spillage from the canal system, particularly the "tail-end escape" on the main canal, is an essential requirement on all schemes. Seepage from irrigation may cause a problem at the junction of the valley slopes and valley-bottom flat-lands or terraces, where a cutoff drain may be required. If a road runs along the foot of the slopes, as is frequently the case, particular attention should be paid to road-side drains and to culverts. However, a formal drainage system from the lower end of every field while technically commendable is not essential in the topography of most Tank commands, and would be opposed by cultivators. It is of greater importance to ensure that natural topographic drainage features are not obstructed, particularly by irrigation channels. Adequate cross-drainage works should be provided wherever canals intersect natural drainage-ways, and culverts wherever access routes cross natural drainage channels.

C.13 HYDRAULIC AND STRUCTURAL DESIGNS

C.13.1 It is not intended to cover hydraulic and structural designs in detail in these notes as the subject is treated in existing Departmental manuals. Selected topics only are discussed.

Dam and Outlet Works

C.13.2 Practices of Irrigation Departments differ in their approach to design of small embankment dams, particularly whether to use relatively steep slopes and minimum volume of fill but with careful attention to quality of fill and internal drainage, or to use flatter slopes with greater volume of fill but less control in selection of fill and placement. With downstream slopes as steep as 1.5 horizontal:1 vertical, as used in the Karnataka Tanks project, material must be carefully selected and compacted, and a vertical (or near vertical) core drain is essential. Where there is any doubt as to possible loss of strength of the fill with time (which can occur with certain soils which are products of recent weathering) slopes should be flatter. In selecting fill for such low dams impermeability is probably less of a consideration than is strength, as the total rate of seepage will be very small indeed with any material likely to be employed.

C.13.3 The traditional outlet is a masonry tower with screw-operated slide gate discharging into a concrete pipe or culvert, extending through or beneath the body of the embankment dam. Use of reinforced pipe is very desirable to prevent or control cracking due to differential settlement of the fill.

C.13.4 A flow-measuring flume downstream of the lower end of the outlet culvert is essential. This should be far enough from the culvert outlet to ensure smooth flow conditions at entry to the flume, but not so far as to be inconvenient to the gate operator who must refer to the flow reading at the flume when adjusting the slide gate.

Flow Measurement

C.13.5 Flow should be measured in the main canal at the outlet from the reservoir as discussed above, also immediately downstream from any branch to a distributary and if required at supplemental points down the length of the canal and/or at the head of minors. Flow should also be measured at the upstream end of each distributary or minor. Measurement may be made at drop structures, by calibration at the point of critical flow at the entry to the drop, but otherwise measurement is by some form of weir or flume.

C.13.6 Desirable features of a measuring flume include installation in such a manner that the flume is operating under "free-flow" or critical flow conditions, i.e. not submerged. Under such conditions water-level need be measured at one location only (rather than at two points as is necessary with the submerged condition), and no reference need be made to charts to read flow. The "free-flow" condition implies submergence of not more than 75%, i.e. a head loss of 25% of the depth in the canal.

C.13.7 A second desirable feature, particularly for measurement on small canals, is continuation of the bed-level of the canal unchanged through the flume (i.e. no raised sill, only restriction of width). Cultivators regard a raised sill as an obstruction to be removed.

C.13.8 Types of measuring device which may be used include the traditional Parshall flume, and the now widely used trapezoidal flume, which is particularly appropriate to small lined canals. Structurally it is simply a transition to a short narrowed throat section, followed by downstream transition back to full canal section. Depth/discharge values for flumes of standard dimension are available, covering the range 0.5 to 60 cfs (15 to 1,700 litres/sec), in the ASAE Tentative Standard S 359T. 1/ Measurement of flow at outlets to watercourses is discussed under "Small Hydraulic Structures".

1/ American Society of Agricultural Engineers.

Spillways and Spillway Channels

C.13.9 Practice on the Karnataka Tanks project is to use the empirical Ryve's formula (derived from study of rivers in South India) for estimation of maximum flood discharge:

$$Q = C M^{\frac{2}{3}} \quad \underline{a}/$$

a/ Q is discharge in cfs; M is catchment area in sq miles; C is a coefficient varying with size of catchment from 650 (0 to 5 sq miles) to 1,250 (1,250 sq miles).

For locations with once-in-100-years one-day rainfall in excess of 17.5 cm the discharge values are increased by 25%. For tanks with Command Area more than 500 ha the Unit Hydrograph method of estimation is used.

C.13.10 The relative merits of the various methods of flood estimation are not discussed here, but it is emphasized that they are estimates only. Although past experience generally supports such estimates as a reasonable provision, they are not absolute maxima. Higher floods have occurred and there have been many tank failures. There is sometimes a margin of additional spillway capacity between discharge at the nominal maximum design level of the reservoir and actual failure by overtopping of the embankment dam. A low masonry parapet on the upstream side of the embankment can reduce the freeboard below crest level required for waves, provided the dam is designed for the full water level.

C.13.11 The spillway and spillway channel represent the major part of the cost of many Tanks. This is particularly the case with a small Tank at the lower end of a series, where the design flood may be relatively great in comparison with the small command area benefitted. Safety against overtopping and failure of the reservoir is undoubtedly the primary consideration. However, subject to that requirement, there are options as to the extent of protection to be provided against the possibility of lesser damage - particularly damage confined to the spillway outflow channel. The choice may be between high first cost, and alternatively lower first cost with possibility of later remedial work being required. Economic viability of a particular scheme may hinge on this question.

C.13.12 In favourable ground conditions, with fractured but otherwise hard rock near to the surface, it may well be sufficient to discharge the spillway outflow into an unprotected shallow channel, accepting the fact that considerable erosion will occur with time until a more or less stable condition is reached. Provided that there is no possibility of head-ward erosion back to the spillway sill this can be a satisfactory solution to the problem.

C.13.13 In less favourable ground conditions weathering may persist to considerable depth, and flood discharge without some form of protection could result in threat to the spillway and embankment. The question is what sort of protection, assuming that a full concrete lining with conventional energy dissipating structure at the lower end of the channel is ruled out on cost grounds. There is no standard answer, although certain observations may be made. An excavated channel, still in relatively erodible material, but with necessary protection on three sides, and the bed arranged as a series of low masonry concrete drop structures and intervening reaches protected by stone pitching, is one possibility. Energy is dissipated en route down the channel with this arrangement and no major structure is required at the downstream end. The lower end is nevertheless the vulnerable area, and particular protection may be required at that point.

C.13.14 Where damage due to settlement or outwashing of material from behind the masonry lining is of concern, added protection can be given by using the rock-filled wire-mesh basket or gabion technique, the individual baskets being wired together to give flexibility with structural continuity. A relatively new construction material which could have application in the ground conditions described is the "geo-fibre" felt, which serves as a permeable core or structural filter to prevent migration of fine material into coarser fill, or through joints. The subject of spillways and spillway channels for Tank schemes warrants considerable further attention.

Canals and Canal Linings

C.13.15 As previously discussed, the canal systems in the Karnataka Tanks project will generally run on/off at full design capacity. (Exception is made in the case of the larger schemes during periods of unusually low supply.) The outlets are fixed, calibrated, orifices designed to give rated discharge when the parent canal is running at design capacity and normal full supply level. The following questions are considered:

a) How closely can the FSL at a particular location on the canal be predicted, for purposes of setting the outlet?

b) How sensitive is the discharge at an outlet to a variation in canal FSL from the design figure?

c) In the larger schemes the canal may run at half rated capacity under conditions of low supply. What influence does this have on head on the outlets and on their discharge?

C.13.16 With regard to the first two questions, given the flow, the gradient of the canal, and the shape of the canal section, and provided that there is no ponding from a downstream obstruction, the remaining factor influencing water-level in the canal is its roughness. Measurements by the Karnataka Engineering Record Station on existing canals of similar capacity and with similar types of lining (concrete slab with mortar jointing) indicates a value of Manning's "n" of approximately 0.020, which is the figure currently being used in designs.

C.13.17 However, the actual value of "n" could range possibly from 0.018 to 0.022 (assuming that the canal is maintained in reasonable condition), i.e. a range of $\pm$ 10%. As depth is approximately proportional to the 0.375 power of "n", other factors being constant, a range of $\pm$ 10% in value of "n" would cause a variation in depth of $\pm$ 3.5%. Corresponding variation in head on the centre-line of the outlet could be 5% to possibly 10% (depending upon the depth of the canal in relation to the depth of setting of the outlet block), and corresponding variation in discharge from the outlet would be 2.5% to 5% 1/ which is acceptable. The actual variation is expected to be less than the range indicated. With regard to sensitivity of outlets to variation in canal FSL, this question is likely to arise if

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1/ Discharge through orifice-type outlets is proportional to square-root of head.

the canal is intentionally operated at more than design discharge, with encroachment on freeboard. As a particular example, a canal of 400 litres/sec normal discharge capacity at 600 mm depth increased to 675 mm, i.e. 75 mm increase, in head on the outlets (a 50% increase) would increase their discharge by approximately 22%, which is of the same order as the increase in canal discharge. Actual relative figures depend upon canal section and other factors, but to a first approximation the outlet discharge increases proportionately to canal flow over the range considered, which is a desirable result.

C.13.18 With regard to operation at half canal capacity, as previously discussed, this is likely to arise only with the larger Tanks (canals of length greater than 5 km) when it is desirable to restrict supply to less than can be accommodated by on/off rotation. Thus, if the filling time is around four or five hours it may be found impractical to operate the canal for less than some three days at a time. If a weekly cycle were to be maintained because of crop sensitivity, a reduction in supply to less than some 40% of maximum rate of supply is the most which could be achieved simply by on-off rotation. Further reduction in rate of supply would require operation of the canal at less than rated capacity. Operation at half capacity is considered.

C.13.19 In these circumstances it is not sufficient merely to reduce the flow at the reservoir sluice by 50%, leaving all outlets on the canal open. Flow to individual outlets would be less than desirable, and there would be inequality between flow at the head-end and the tail-end of the canal (the latter taking the greater share in these circumstances). It would in fact be necessary to rotationally close the outlets, first closing those in the upstream half of the canal, then those in the downstream half. With the upstream outlets closed the flow being delivered at the mid-point of the canal would be rated discharge (one half rated discharge at the reservoir, with no outlets open in the upstream reach, is equivalent to full rated discharge at mid-point). The water levels in the downstream half of the canal, and head on outlets and outlet discharge, would then be the same as for normal full-flow operation, and no special provision is required. However, when supply to the downstream half of the canal is shut down by closure of a check gate at the canal mid-point, and the upstream outlets are opened, the situation encountered is not the same as described above for operation of the lower half of the system. The upper portion of the canal is operating at half capacity, and unless special provision is made the head on outlets would be substantially reduced, and reduced unequally.

C.13.20 The special provision required is a check structure below each outlet or pair of outlets to control head on the outlets under these conditions. As there are unlikely to be more than ten or twelve outlets in the upstream half of a main canal, and as the check structures are small (depth is usually less than 0.75 m) such provision is not a major cost or operational item. Needle beam checks would be appropriate. These could be installed after construction of the canal, and entirely within the lined section. It is noted that simple fixed duck-billed weirs are not a solution in the situation discussed. The checks must be re-adjusted when normal full-flow operation is resumed.

C.13.21 With regard to canal linings, a considerable range of materials and types of design are in use in India, and it is not proposed to review all of the possibilities at this time. The lining proposed for the Karnataka Tanks, in most areas, is of pre-cast concrete slabs with shaped inter-locking edges. The edge detail is being formed with precision (by use of a fine-mix around the edges of the mould). It prevents displacement of one slab with respect to its neighbour due to soil movement or pressure of plant roots, a frequent cause of incipient failure. It also prevents theft. The bottom detail (junction of sides and floor slab) is such as to prevent kicking out of side slabs - they are retained by the bottom slabs. Careful placement of mortar across the full thickness of the slab at the joint is necessary. Use of a plastic sheet behind the lining is also under consideration. Other types of lining, including stone-slab with mechanical interlock between slabs, are discussed in detail in Annex B1.

C.13.22 Side-slopes of lined main canals are 1 horizontal:1 1/2 vertical in normal ground conditions. In heavy cracking clay soils over-excavation and backfill with granular material is practised. However, where there remains concern over lateral soil movement slopes should be laid back to 1:1.

Linings for Watercourses/Field Channels

C.13.23 Refer also to discussion in Annex B1.

Small Hydraulic Structures

C.13.24 The structures referred to are outlets, turnouts, drops, checks, division boxes, etc., on watercourses or field channels. Problems with such structures include the following:

- Damage by soil stresses, particularly in cracking clay soils.
- By-passing through shrinkage cracks in soils.
- Theft, including theft of gates.
- Malicious damage, tampering, and unauthorized operation.
- Cost.
- Slow rate of construction.

C.13.25 The last two items rule out the use of traditional heavy masonry or brick construction where structures are required in large numbers. The alternative is some form of pre-cast construction, or a combination of masonry and pre-casting. Durability is the primary consideration generally implying substantial structures, and weight. Considerable ingenuity is being exercised in the design and manufacture of small structures by those concerned, and such initiative deserves every encouragement.

C.13.26 The outlet block proposed (Plate 5) calls for some comment, as it is an important structure and is required in large numbers. Hydraulically it is simply a fixed orifice, which is either produced in standard sizes according to size of delivery stream required, or if preferred can be produced with a single (largest) opening and the opening reduced at site by mortar-plastering against one of a set of standard steel orifice templates, according to capacity required. Alternatively a steel plate with orifice of required size for the particular outlet can be inserted permanently between the block and the culvert pipe. The "gate" is normally a simple concrete slab, or a natural stone slab if necessary. It lies against the sloping face of the outlet block when in use. In normal operation the gate will only be required when cultivators served by an outlet wish to shut off supply. An alternative (for use in larger canals) employs a light welded steel frame which bolts to studs in the sloping face of the block and accommodates a sliding steel leaf which may be locked open or closed. The water-level in the watercourse immediately downstream from the outlet should be low enough to ensure that the outlet orifice operates "unsubmerged", i.e. the level in the culvert pipe should be below the top of the outlet orifice by at least 30% of the orifice diameter. Provided that the downstream end of the outlet pipe is installed so as to operate with free-flow (not submerged), as will normally be the case, the depth of flow leaving the pipe will provide a measure of rate of flow.

C.13.27 The R.C. check structure (Plate 7) is a useful multi-purpose component which can be used in the applications indicated. With supplementary natural stone slab cutoff it is proof against by-passing in BC soils. It is designed for closure by concrete slab, stone slab, or if necessary by brushwood.

C.14 OPERATION OF TANK SCHEMES

Method of Allocation of Water to Cultivators and Scheduling of Water Deliveries

C.14.1 Methods of allotment of water to cultivators being practised in India include allocation on a per hectare basis or alternatively on the basis of applications and authorization for specific crops. Methods of scheduling of deliveries also vary. Comparison or evaluation of the alternatives is not proposed in this paper. It is emphasised, however, that methods of allocation or operation are not necessarily committed at the time of project design and construction. Within limits, the project facilities may be operated in a number of ways. One of the few restrictions built into the system proposed is equality of water allocation between outlet commands, on an area basis, but not necessarily within an outlet command, although even the former could be varied either at the time of initial design or by replacement and change in capacity of a particular outlet. The more essential feature is that all outlets work for the same period of time, and together.

C.14.2 The system proposed is designed to permit rates of supply varying from the design maximum down to a much smaller rate (25% of maximum or less) while still retaining weekly water application at the outlet, and at the farm if desired. Planning of areas to be irrigated and scheduling of supply to outlets will probably be done at the beginning of each season, after due consultation with the cultivators concerned. However, unpredictable variation in availability of water, particularly in the monsoon season, may call for changes in scheduling of releases and should not present a problem in view of the relatively small number of cultivators involved or affected by such decisions, in a Tank scheme. The scheduling of releases is discussed further in Annex C4.

Role of Cultivators in Operation and in Maintenance of Works

C.14.3 As the response of a particular group of cultivators to the prospect of taking some degree of responsibility in the management of their Tank scheme can only be judged after the event, discussion of the role of cultivators is necessarily more philosophical than factual. It is certain that any scheme, large or small, will require close Departmental support in its initial two or three years of operation, and this should not be restricted by norms as to regular staffing levels. There should be a clear understanding of "who does what and when" initially. The extent to which management and maintenance may be later transferred to cultivators will be determined by experience.

Groundwater Development in Association with Tanks

C.14.4 A valuable adjunct to Tank irrigation is frequently the area under year-round irrigation of perennials, vegetables, etc., from groundwater (dug-wells and small tubewells) immediately below the dam. To be included in this category are crops such as plantains and sugar-cane in the lower lying area of the command, which benefit from the higher water-table resulting from irrigation of adjacent upper areas. Expansion of this area of generally high value cash crops is to be encouraged, and it should be regarded as an integral part of the project command, with supplemental irrigation from the canal system if indicated.

C.15 SEDIMENTATION AND CATCHMENT PROTECTION

C.15.1 Sedimentation has eventually closed out the useful life of very many Tanks in India, and greatly reduced the value of many more. As the catchment of a Tank is often mainly in uncultivated sparsely forested lands the erosion which contributes to sedimentation of the Tank goes on largely unheeded. Full conservation treatment of the catchments of all new Tanks would indeed be desirable, but would be a major task and is not immediately in prospect. However, selective treatment of local areas where aggressive erosion is occurring (particularly headward erosion of nullahs) would do much to reduce the rate of siltation. This should be undertaken during construction of the scheme, being regarded as an integral part of the work and being budgeted accordingly.

ANNEX C1

ECONOMIC CRITERIA

1. Individual Tank schemes of the Karnataka project were required to have an economic rate of return of not less than 12%. However, in view of the large number of schemes to be investigated an alternative to the conventional method of economic analysis was developed during appraisal. The approach adopted is of considerable interest and could be widely used in investigation of irrigation projects generally, at least as an approximate check on viability.

2. In principle, the cost per cubic metre of water made available at reservoir outlet in the design year was estimated, and compared with the value of that water in terms of the agricultural production attributable to it, less costs of production.

3. The net economic value of incremental production per cubic metre of water was obtained from study of representative cropping patterns in typical climatic zones (average for the project was Rs0.54/m3). The present worth of a series of such annual benefits, less operation and maintenance costs, was then estimated, taking into account the length of the construction period (four different periods were taken, varying from 2 to 5 years). A discount rate of 12% for 30 years was used in this calculation. In a typical case for a two-year construction period with an average value of water of Rs0.54/m3 the present value of the series of such annual benefits, allowing for annual O and M costs, was Rs3.7/m3. This is an economic value. For comparison with actual (financial) cost of construction, adjustment is necessary to take into account the fact that the economic cost of construction is less than the financial cost by a construction conversion factor (reflecting the difference between actual labour costs and opportunity cost of labour). This factor was calculated at 0.78 in the Karnataka case. Applying this factor and a 5% "margin of error" to the economic value of Rs3.7 gives an equivalent financial value of Rs5/m3 which is the "cut-off" point for the present value of the capital cost of providing 1 m3 per annum in perpetuity (the figures are for 1981).

ANNEX C2

YIELD HYDROLOGY - ESTIMATION OF MONTHLY DISTRIBUTION OF MONSOON SEASON

1. As discussed in the text, where actual flow records are not available for the stream under investigation, nor for a similar catchment which could be used for purposes of correlation, Strange's coefficients are used on the Karnataka project for estimation of "50% probable" seasonal runoff. Runoff in individual monsoon months varies widely from year to year, and use of mean monthly values has limited value. Nevertheless some indication of monthly distribution of runoff through the monsoon season is needed in planning.

2. Runoff is certainly less per inch of rainfall in the earlier monsoon months than in late monsoon, due to higher infiltration into the drier soils of the catchment in the early months. Distribution of runoff in proportion to monthly precipitation consequently over-estimates runoff in the early part of the season.

3. The approach used in the Karnataka project is based on further work by Strange on runoff from individual streams falling upon dry, moist or wet catchments. In effect rainfall is "weighted" by a factor of 0.5 in June, 0.8 in July, and unity thereafter. The following case will illustrate. Total seasonal runoff is estimated at 250 mm by the conventional Strange's factor approach (a factor of 33% in this case).

	June	July	August	Sept.	Oct.	Total
Actual Mean Monthly Rainfall (mm)	75	200	200	125	150	750
Weight Factor	0.5	0.8	1.0	1.0	1.0	
Weighted Rainfall (mm)	37	160	200	125	150	672

Calculated Runoff (mm)

June $\frac{37}{672} \times 250 = 14$

July $\frac{160}{672} \times 250 = 60$

Aug. $\frac{200}{672} \times 250 = 74$

Sept. $\frac{125}{672} \times 250 = 46$

Oct. $\frac{150}{672} \times 250 = 56$

Total 250

ANNEX C3

DETERMINATION OF OPTIMUM STORAGE CAPACITY OF RESERVOIR

1. The factors influencing selection of reservoir capacity at a particular site are discussed in the text. Of considerable importance is relative cost of storage capacity, more particularly the incremental cost of storage, over the range of capacity which could be considered.

2. The economic approach to assessment of desirable reservoir capacity compares cost of reservoir with benefits resulting from it. More specifically the height of the dam is carried up to the point at which the cost of increasing height by a further foot would just equal the benefit derived from that additional foot of storage. In general reservoir capacity is relatively costly per unit of storage if the height of dam is small. It becomes less so as the height of dam increases, and finally again becomes more costly as the height is carried up to the stage of "running out of topography", at which point the length of the dam becomes excessive. The curve of reservoir capacity vs cost is purely a function of damsite and reservoir topography. On the other hand the regulated supply of water which may be made available annually from a given source by provision of storage is relatively great (incrementally) at small levels of storage, and becomes smaller with increasing storage. The curve of storage capacity vs regulated flow is purely a function of the shapes of the inflow and desired outflow (irrigation draw-off) hydrographs. If regulated flow is given a unit annual value, and capitalized, the curves of cost v capacity and value v capacity can be plotted together. At the capacity where they cross the total cost of storage equals the total value of the regulated flow resulting from that storage. However, the indicated economic limit stops short of that value and is given by the amount of storage at which the cost of an increment of additional storage capacity equals the capitalized value of the additional regulated supply of water resulting from that increment of storage.

3. In the case of Tank schemes it is desirable to apply the logic of the above system of determining reservoir capacity, but with a degree of simplification appropriate to the limitations in reliability of available data, the considerable number of projects involved, and their relatively small size.

4. The items to be considered are the following:

a) Graphical presentation of cost of reservoir as a function of storage capacity;

b) Graphical presentation of annual amount of regulated supply of water as a function of storage capacity of reservoir;

c) Value per unit of regulated water.

These are discussed further overleaf.

ANNEX C3

Cost of Storage Capacity

5. Preparation of item (a) involves estimation of cost for at least three heights of dam. Because many items such as river diversion, access roads, and camp establishment vary little with dam height, the simplest procedure is to prepare a complete cost estimate for one height of dam, selected by judgement as being within the general order of height anticipated, and to determine the incremental cost or savings in varying the height up or down by 10 to 15%. The change in cost will lie largely in the structure of the dam itself, and in reservoir land acquisition and resettlement cost, estimation of both of which is relatively straightforward. One complication which may be encountered, however, is a change in indicated location or type of spillway if dam height exceeds a certain level. This may cause a change in slope of the reservoir capacity vs cost curve at that point, in which case costs at two dam elevations below and two above that point would be required to establish the slopes of the two portions of the cost curve.

6. The amount of work involved in establishing an approximate capacity/cost curve, above that required in any case for basic project estimates, is small in most cases.

Regulated Supply vs Storage Capacity

7. In the following discussion it is assumed that reservoirs of Tank schemes are not designed to carry forward storage from one monsoon to another. They provide regulation within a twelve-month period only, and are generally empty at the beginning of the monsoon season each year. As a first approximation the amount of water available for storage can be taken as the "50% probable" monsoon yield less anticipated irrigation diversions during the monsoon months. Adding storage capacity will increase available stored water up to the limit of water available. For closer estimation it would be necessary to prepare estimates of monsoon yield figures for a hydrologic period of several years, and to check in each year the amount of water which would be held in storage at end-monsoon, for each of several capacities of reservoir. An average amount of annual storage can then be calculated for each of the reservoir capacities.

8. The unit values per cubic metre to be applied to the stored water are obtained from typical cropping patterns as discussed in Annex C1.

ANNEX C4

OPERATION OF MAIN CANALS AND SCHEDULING OF DELIVERIES TO THE FARM SUPPLEMENTAL NOTES

Introduction

1. The following notes cover a number of items relating to canal capacity, operation of canals and scheduling of deliveries to the farm under various conditions of water availability and crop water demand.

2. The operation of the canal and field-channel system, with its associated farm turnouts, is determined by the following factors:

- The amount of water available (in the rabi season this is the end-of-monsoon storage).
- The capacity of the canal.
- The crops being grown, the crop water demand, and the timing and frequency of irrigation desired by farmers at the particular stage of the season.

Capacity of Main Canal

3. Various approaches to determining and checking main canal capacity are discussed in the paper. The rule-of-thumb formula, although a generalized approach, fits most circumstances quite well. In effect, the formula gives the canal-head capacity, or duty for continuous operation as:

$$(0.7 + 0.5\ p)\ \text{litres/sec/ha}$$

The factor "p" is the proportion of the command under paddy. In practice sugar-cane is being included with paddy in determining the factor "p". Capacities so determined range from 0.7 litres/sec/ha for non-paddy schemes to about 1.1 litres/sec/ha for schemes with up to 90% of the command under paddy. In fact, apart from four purely paddy schemes in the high rainfall area and one purely sugar-cane scheme, the design percentage of paddy in the command is generally less than 30%.

4. Assuming the latter figure, the question of where the 30% of the area under paddy will be located within the command, and how to prevent cultivators from planting more paddy and demanding water for it has been much discussed. The answer to the first half of the question is clear. It is not intended to designate particular portions of the command as paddy areas, i.e. to "localise" areas for paddy, and to provide a special allocation of water for such areas. All cultivators will share equally in the water available. A cultivator with part or all of his holding in a lower-lying situation with heavier soils, in which natural runoff and seepage create conditions favourable for paddy and requiring comparatively limited supplemental irrigation, is likely to grow paddy on a part or possibly all of his holding. The proportion of the command planted to paddy

in any particular season will be influenced by the amount of rainfall in early monsoon, and judgement of cultivators. There can be no assurance early in the monsoon that conditions will be such that 30% of paddy or any other percentage can be sustained. The 30% figure is purely an assessment at the time of design as to the proportion which is likely to be possible in an average year, with the anticipated rainfall in the command and yield from the catchment. The only permanent significance of the figure is that it is used in determining canal capacity.

5. With regard to cultivators demanding more water for paddy, and possibly making unauthorised diversions from the canal, as the canal has to be operated continuously, or with short irrigation interval, on account of the paddy legitimately being grown in the area in the kharif season in the case referred to, paddy cannot be controlled by periodic shut-down at the canal. It has to be kept in operation. With respect to unauthorised diversions, as a Tank is a communally owned facility with the available water visible and shared by all, the cultivator demanding more than his share would have his neighbours to contend with. Unauthorized diversions may occur, but communal discipline against the offender, particularly in periods of deficiency, probably inhibits such action.

6. Demand for water and unauthorised diversions for paddy are unlikely to be a problem in rabi, as temperatures are too low for paddy in that season, except in coastal areas. Furthermore hot-weather paddy is not a possibility in Tank schemes as reservoirs are likely to be empty before such a crop could mature. Deterrence of paddy is consequently not a problem to be taken into account in canal operation in the rabi season.

7. However, in those Tanks (the majority) in which it is planned to grow entirely non-paddy crops in the kharif season scheduling of "off" periods in canal supply may be necessary as a deterrent to paddy cultivation. It will not necessarily eliminate it, as in low-lying heavy soil areas paddy can survive a two-week break in irrigation in the kharif season equally as well as can non-paddy crops in lighter upland soils. However, a rotation for part of the season (not necessarily the peak period) would effectively prevent cultivation of paddy in other than the low-lying portions of the command. Such rotational supply is possible without increasing canal capacity on that account. Thus, with the minimum capacity obtained using the formula (0.7 litres/sec/ha) the effective rate of supply over a 50% "on"/"off" cycle is 0.35 litres/sec/ha of command, which is equivalent to 3 mm/day. Together with even minimal monsoon rainfall this is in fact sufficient for kharif non-paddy crops, even with kharif crop intensity of 100%. During a possible short-term peak demand for pre-cultivation irrigation (over some 15 days) the canal could run continuously, thereafter reverting to on/off.

8. In the rabi season (in March particularly) water requirements are higher, and a canal with capacity 0.7 litres/sec/ha would need to run continuously if the rabi cropping intensity was as high as 100% and there was sufficient reservoir storage to meet that intensity (which is unlikely). However, as discussed earlier on/off rotation of canals to inhibit paddy cultivation is not a requirement in the rabi season and continuous canal operation is not a disadvantage. The remaining requirement for rabi crops is a pre-cultivation irrigation of some 75 mm required possibly throughout the command within a 15-day period. This, as far as the main canal is concerned, is an average of 5 mm/day. As a capacity of 0.7 litres/sec/ha is equivalent to 6 mm/day at canal head, this requirement is also met.

9. To summarise, canals in the larger Tanks can be designed for the 0.7 to 1.2 litres/sec/ha according to the proportion of paddy with continuous operation in the peak season. It is not necessary to provide for on/off rotation in the peak season to inhibit paddy. The latter consideration only arises during the kharif season in those schemes which are designed for purely non-paddy crops, and in those circumstances kharif irrigation requirements can be met with on/off rotation of the canal, without the provision of additional capacity above the figure of 0.7 litres/sec/ha.

10. In the case of small schemes operating in daylight hours only (12 hours on/12 hours off) the same reasoning applies. The capacities, however, are doubled to the range of 1.4 to 2.4 litres/sec/ha. Again the canal is designed to run every day in the peak season, not rotationally. It is noted that a system designed for 12 hours on/12 hours off has, in any case, a considerable built-in reserve of capacity. Thus, by changing the cycle to 16 hours on/8 hours off the daily conveyance capacity is increased by 33%. There may be a case for providing greater capacity than that above for certain small schemes in the interest of reducing the size of the outlet commands, where indicated by topographic factors. This increase in turn implies rotational operation even in the peak, but such operation is a result of the increased capacity, but it is not the reason for it.

11. A final point on canal capacity. The Minor Irrigation Department guideline suggests adding 20% to the capacity determined from cropping pattern and crop water use calculations. This is a reasonable provision. However, capacities calculated by the Bank formula should be taken as the design basis for canal design and setting of outlets, without addition of a further factor. The Tank canals do, however, have additional capacity available (up to 20-25%) with the freeboard range, and outlets similarly.

Scheduling of Water Delivery to Farmers

12. While a nominal "design" cropping pattern is used for project analysis, considerable freedom of choice by the cultivator in selection of crop and in pattern of irrigation is proposed, subject to the constraints imposed by operating within a communal system, and to the guidance of the Taluk Committee. The design cropping pattern assumes a particular proportionality between kharif and rabi crop intensity, and indirectly between use of available water in the two seasons. In actual operation this proportioning of water use between kharif and rabi will be determined year by year, taking into account collective preferences of cultivators and the views of the Committee. It is not proposed to "localise" specific areas for

kharif and for rabi crops. Cultivators will have opportunity for both if they so desire. The crop periods do not overlap; kharif and rabi crops can be grown in sequence. While the design cropping pattern refers to particular seasonal irrigation intensities, for instance 60% rabi, it is not to be inferred that a block covering 60% of the command will receive water sufficient for irrigation of the whole of that area, with none on the remaining 40% of the command. As all cultivators will be entitled to receive equal shares in proportion to area, the 60% intensity will be on each farm, i.e. each cultivator would receive sufficient water to fully irrigate 60% of his holding. In fact the design irrigation intensities are indicative only. Individual cultivators may use their share of the water for light irrigation of their entire holding or for heavier irrigation of a portion of it, but always with the constraint that all outlet commands receive the same amount of water per unit of area, and that they all operate together. Within the outlet command, however, there is considerable room for adjustment between neighbours as to duration and frequency of watering by individuals, provided that equality in seasonal totals is preserved.

13. Scheduling of operation of the main canal, particularly in the off-peak periods when operation will not be continuous, has to have regard to the needs of different cultivators with considerably different crops.

14. As an example, consider a cultivator growing jowar in the rabi season on a 1-ha holding. His share of the end of monsoon water in storage, which is assumed for the purpose of discussion to be equivalent to 300 mm depth over the whole command, is 3,000 m3. He may want to divide this into a 75 mm (750 m3) pre-cultivation irrigation and three similar irrigations at monthly intervals. However, his neighbour may wish to grow vegetables on a portion of his holding and his main concern would be to have a lesser quantity of water delivered at fortnightly intervals, still totalling 3,000 m3 for the season. For convenience in discussion it is assumed that the canal has a design duty of 0.7 litres/sec/ha, and that the delivery stream is 20 litres/sec, with corresponding size of outlet command of 28 ha.

15. To deliver an initial pre-cultivation irrigation of 75 mm throughout the whole command would require operation of the canal for 12.5 days (as 0.7 litres/sec/ha is equivalent to 6 mm/day). All outlets would run for that period, and the cultivator with 1 ha could take the whole delivery stream of 20 litres/sec for 1/28 x 12.5 days or approximately 11 hours, giving him 750 m3 (as 20 litres/sec is equivalent to 72 m3/hr). Alternatively by arrangement with his neighbours, he could take the delivery stream for 5 1/2 hours in the first week, applying it to one-half of his holding which he would then proceed to cultivate, and for 5 1/2 hours in the following week when he would irrigate the other half. For subsequent irrigations, if an application of 750 m3 is required once per month, the canal could again be operated for 12.5 days and the cultivator could take his whole share for that month in one watering of 11 hours, or in two of 5 1/2 hours during that period.

16. However, if his neighbour growing vegetables is to be considered, the canal should be operated once fortnightly rather than once monthly, and for 6.25 days each time rather than 12.5. Each cultivator (assuming both have 1 ha) would be entitled to 1/28 x 6.25 days or 5 1/2 hours of irrigation in each fortnightly irrigation. The jowar cultivator would probably use it to apply 75 mm on one-half of his holding each fortnight, alternating with the other half, or by exchange with another cultivator with similar crop he could take water once monthly (for 12.5 hours). The vegetable cultivator, probably using furrow irrigation or furrow-in-a-bed might choose to apply 37 mm over his entire hectare each fortnight. (Such light irrigation is quite practical with furrow cultivation, and is preferred for shallow-rooted crops.)

17. The above discussion refers to a normal season. Should the amount of water in the reservoir at the beginning of the rabi season be equivalent to only 150 mm over the command, then cultivators would have to decide on fewer irrigations or the same frequency of irrigation but smaller duration. With the vegetable grower in mind the second alternative would probably be preferable, the canal operating for three days each fortnight instead of six. Each 1-ha cultivator would be entitled to approximately 2 1/2 hours of irrigation (1/28 x 3 days) each fortnight. The jowar cultivator might again choose to arrange with another to exchange fortnightly entitlements, each irrigating for 5 hours once a month but on alternate fortnights. The duration of canal operation per fortnight, taken as uniform throughout the season for purposes of discussion, would in fact vary from month to month in accordance with crop demand.

18. With small Tanks operating only in daylight hours the situation is similar. The capacity of outlet (the delivery stream) remains 20 litres/sec. However, the canal capacity doubles to 1.4 litres/sec/ha and the area of outlet command is halved to 14 ha (there are twice as many outlets for a given area of command, compared with 24 hourly operation of a larger canal). The 1-ha cultivator previously entitled to 5 1/2 hours of delivery each fortnight is still entitled to that amount. A larger cultivator with 4 ha would be entitled to 22 hours, but would have to take 12 hours on one day, and 10 hours the next as the canal only operates for 12 hours per day. However, with small canals operating in daylight only the option of a weekly rotation is also available, with the canal operating for 3 days per week instead of 6 days per fortnight (figures are rounded) and the 1-ha cultivator taking water for 2 3/4 hours once per week instead of 5 1/2 hours once per fortnight. Again, the jowar cultivator could, by exchange, take his allocated hours fortnightly.

Operation in the Kharif Season

19. The above discussion refers to the rabi season, when the total amount of water available at the beginning of the season each year is known (i.e. the contents of the reservoir). Decisions can, and should, be taken in advance as to which crops are to be grown both for the command as a whole and by individual cultivators. A schedule of canal releases can then be worked out, establishing dates and periods of supply to each outlet. It is also desirable for rotational schedules within each outlet command to be worked out by the cultivators which it supplies.

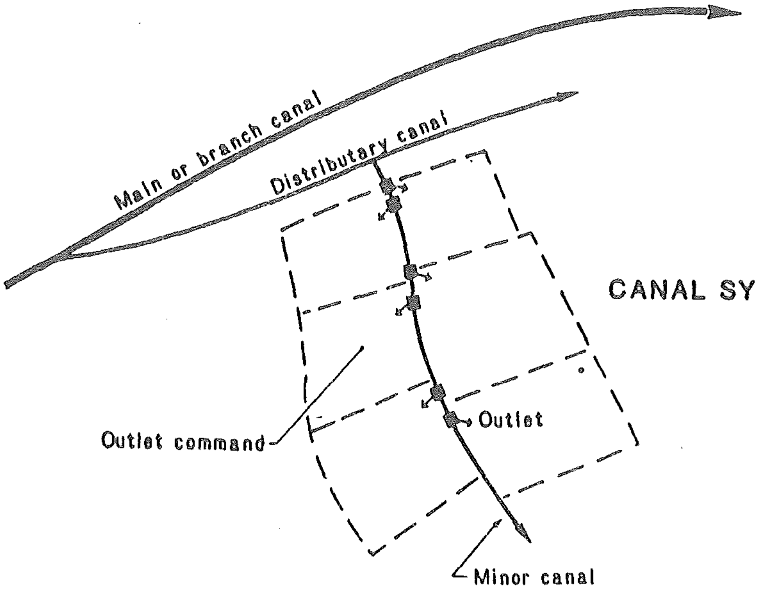
20. During the initial year or two of operation of a scheme, cultivators may need guidance in setting up rotational schedules within the outlet command, or an arbitrary rotational schedule may be suggested to them until their individual preferences develop and each outlet command prepares its own schedule. It is noted that in the larger commands it is of advantage for the command to be considered as divided, for operational purposes, into sub-areas each served by the turn-outs within that sub-area. In scheduling of rotational supply within the outlet command, times are established for supply firstly to each sub-area, and secondly among farmers within each sub-area. This is an administrative arrangement which can be instituted at any time. It will not be necessary in the smaller commands (10 to 15 ha) of the "daytime only" schemes.

21. The scheduling of canal operation in the kharif season is less predictable than in the rabi, due to uncertainties as to the incidence of rainfall. The role of irrigation in that season is largely to supplement rainfall to the extent that water is available. As catchment and the command are in the same vicinity in Tank schemes, a deficiency in rainfall in the kharif affects both. Consequently, as carry-over from the previous year is not proposed in Tanks, supplemental irrigation in early monsoon is not usually available. Decision on when or whether to irrigate later in the kharif season, versus storing for rabi, will depend upon crops being grown in both seasons, and the condition of the kharif crops at the time. It is not a decision which can readily be taken in advance, based on a standard set of possible situations, as there are many variables (including relative market prices for kharif and rabi crops). However, rotational schedules within each outlet command can, and should, be established in advance for a typical 75 mm irrigation application over the command in 14 days, or a lesser application over 7 days. Whether such watering will be required, or when, will depend upon the course of the monsoon rains and other factors.

PLATE 1

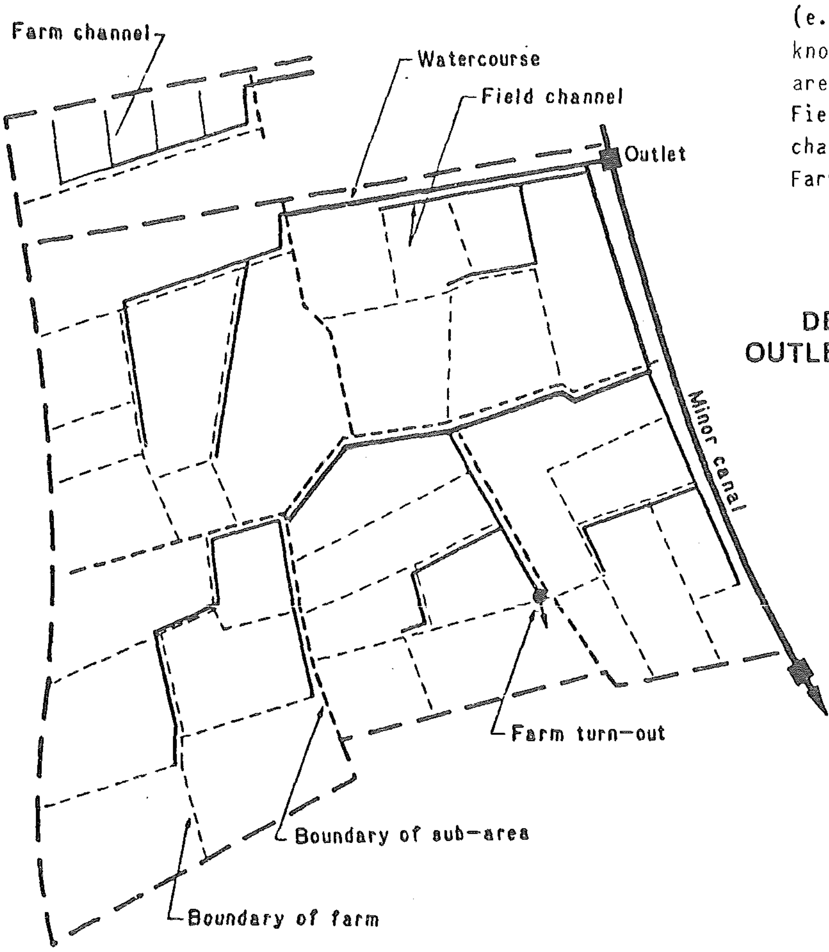
DESIGN AND OPERATION OF IRRIGATION SYSTEMS FOR SMALLHOLDER AGRICULTURE IN SOUTH ASIA. VOL. I

NOMENCLATURE FOR CANAL DISTRIBUTION SYSTEM



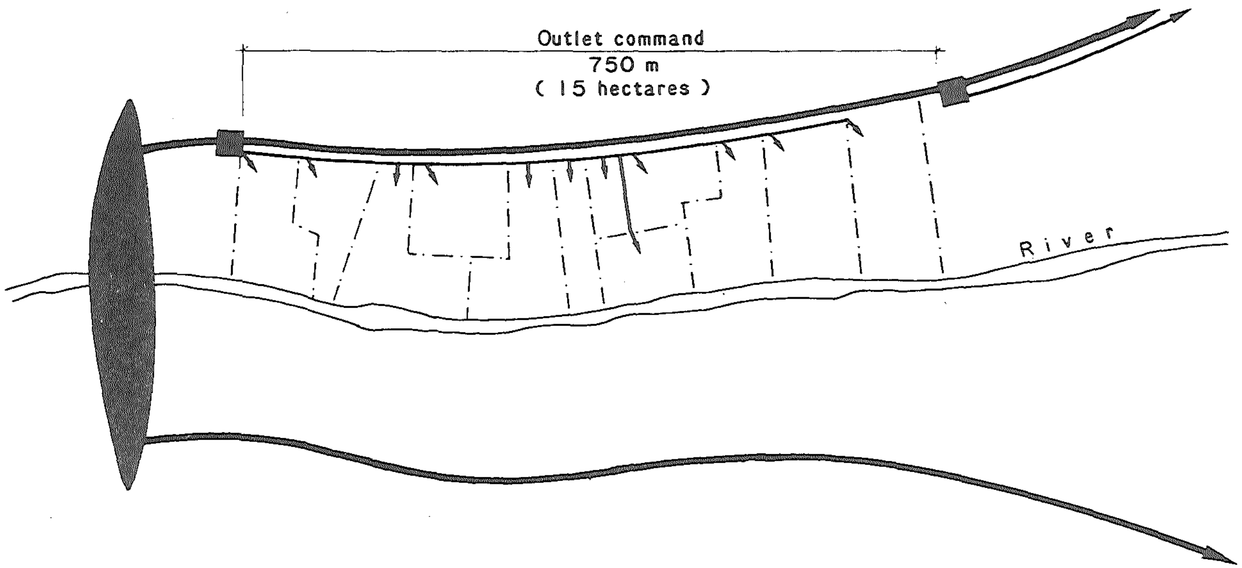
CANAL SYSTEM

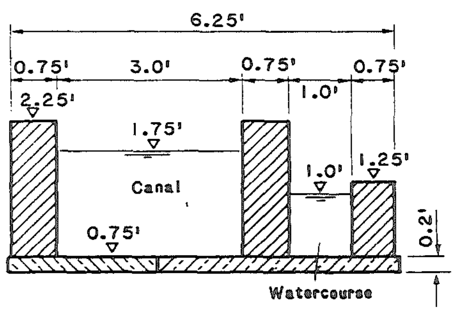
Note: In some regions (e.g. Karnataka) Minors are known as laterals, Watercourses are know as Field channels, Field channels as Branch field channels, Farm turn-outs as Farm gates.



DETAIL OF
OUTLET COMMAND

LAYOUT OF WATERCOURSE FOR NARROW OUTLET COMMAND ON VALLEY-SLOPE





DETAIL OF COMPOSITE FLUME - TYPE STRUCTURE FOR CANAL AND WATERCOURSE

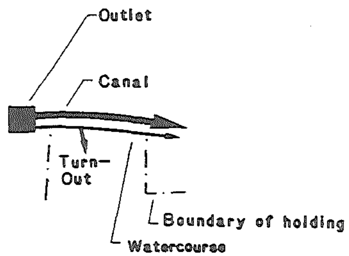


PLATE 2

DDC885-619

PLATE 3

DESIGN AND OPERATION OF IRRIGATION SYSTEMS FOR SMALLHOLDER AGRICULTURE IN SOUTH ASIA. VOL.I

LAYOUT OF WATERCOURSE SYSTEM ON NARROW SPUR

FIG. 1

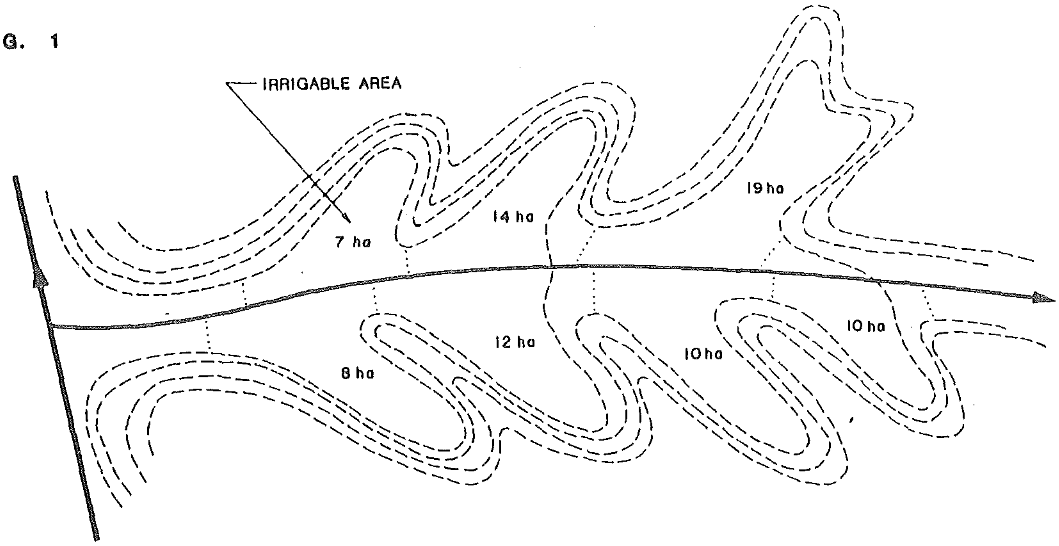


FIG. 2

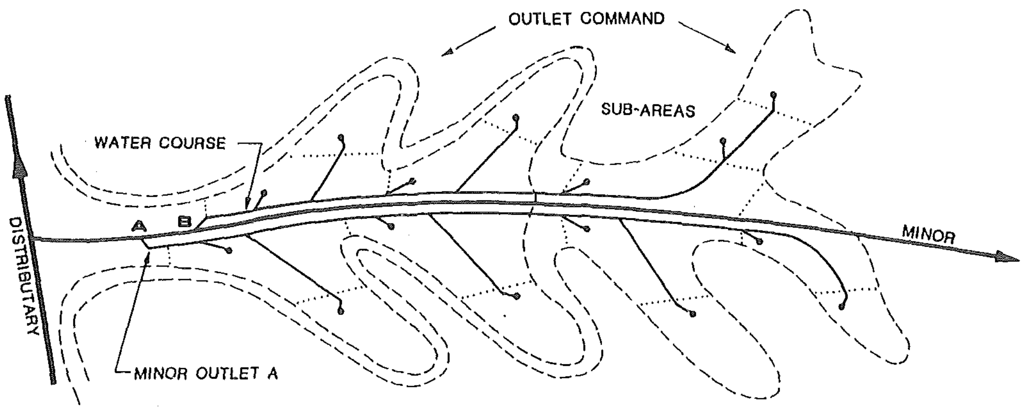
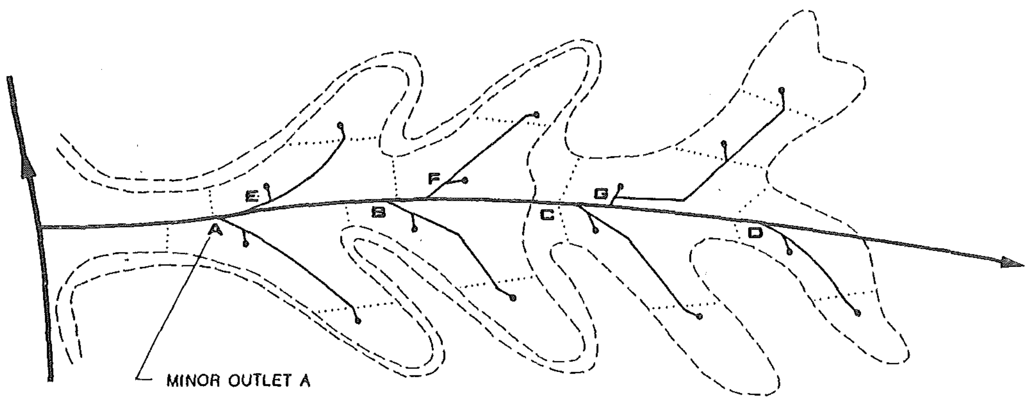


FIG. 3



SCHEMATIC LAYOUT OF DISTRIBUTION SYSTEM OF PART OF LEFT COMMAND

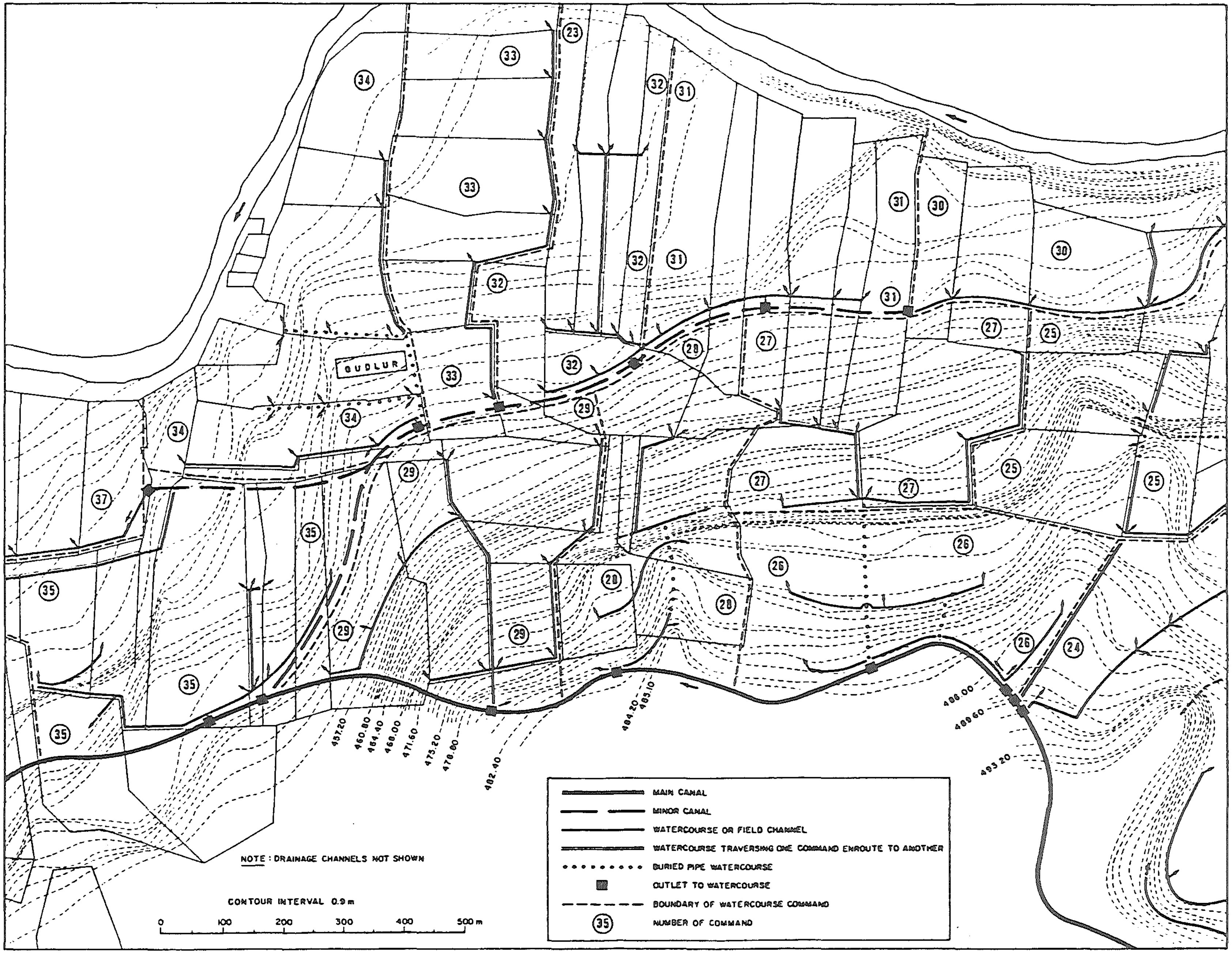


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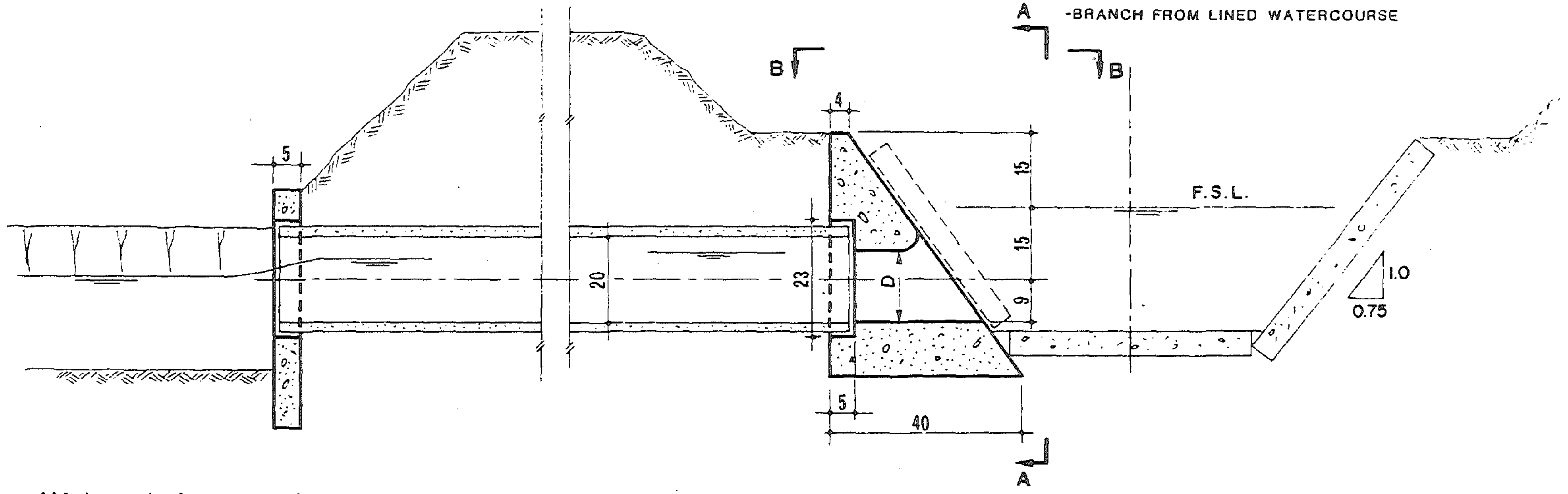
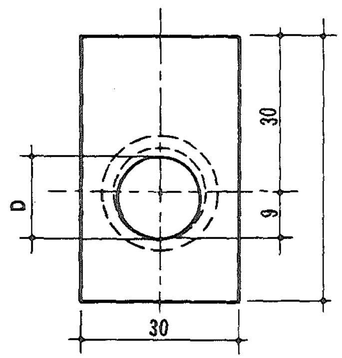
PLATE 4

OUTLET FROM MINOR CANAL

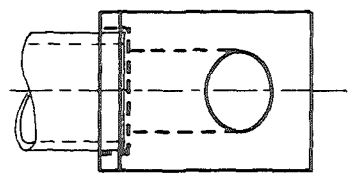
-LINED CANAL TO LINED OR UNLINED WATERCOURSE
-TURNOUT FROM LINED WATERCOURSE TO FIELD CHANNEL
-BRANCH FROM LINED WATERCOURSE



1. Diameter D will be made in range of sizes from 9 cm to 15 cm to suit range of desired outlet capacities (up to 35 l/s).
2. When used as full-flow turnout or branch D = 17.5 cm (approx. 7 ").
3. An alternative arrangement is for the outlet block to be of standard diameter and a steel orifice plate with opening of desired size inserted between the block and the culvert pipe.



ELEVATION A - A



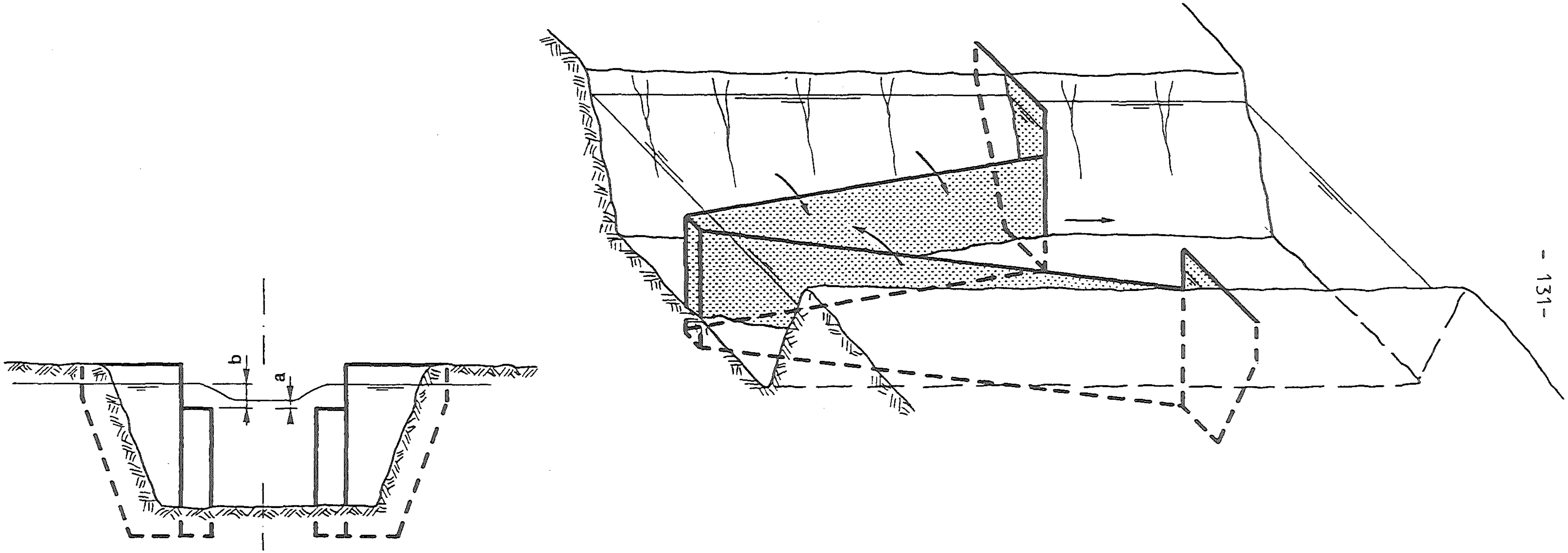
PLAN ON B - B

0 10 20 30 40 50 cm

PLATE 5

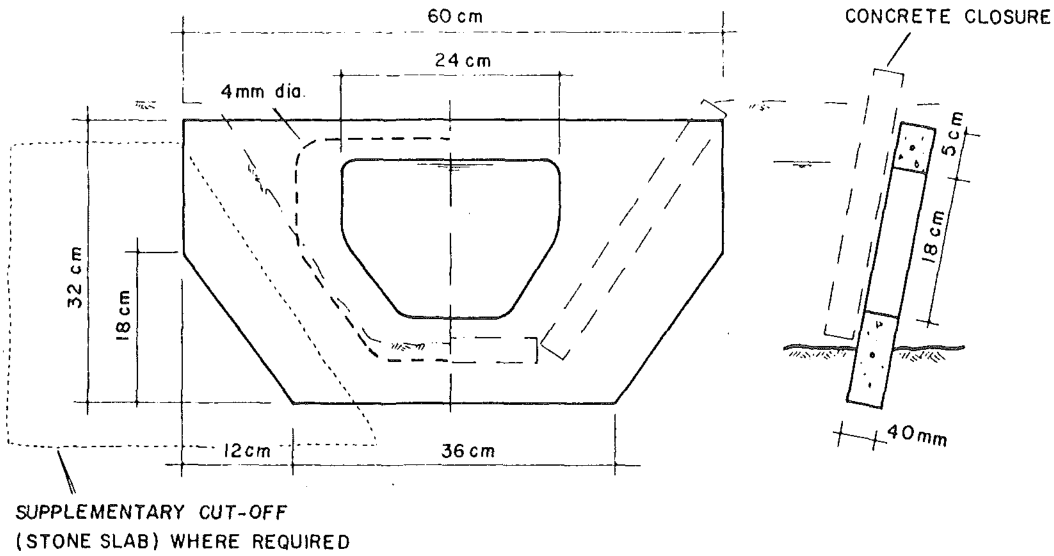
FOR MEASUREMENT OF FLOWS IN UNLINED WATERCOURSES. SCHEMATIC OF PORTABLE, DUCK-BILL WEIR

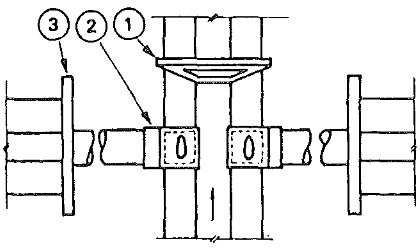
(FLOW 15 to 30 l/s)



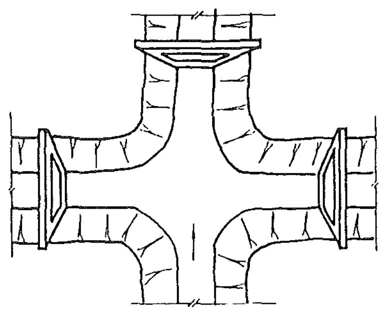
The weir is of heavy gauge sheet steel, the five components being joined by hinges, permitting them to lie flat when being carried. The joints are sealed by adhesive tape. Total length of the overpour section is about 1 metre. The weir should be installed with the crest at about one inch below the normal operating level in the channel. The upstream level will then back up to about 30 mm above normal. The angle between the arms of the Vee is not critical, and may be adjusted to suit the width of the channel. The weir permits measurement of flow where very little hydraulic head is available (about 30 mm). The weir should be calibrated with approximately 40% submergence of the nappe (ratio a/b in above sketch) and will normally be operated in that condition to minimize back-up of upstream water-level.

PRE-CAST R.C. CHECK STRUCTURE AND APPLICATION

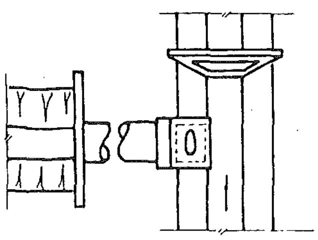




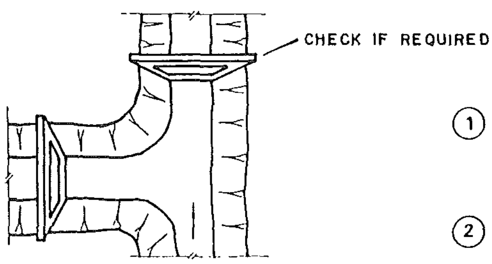
THREE-WAY BRANCH. LINED FIELD CHANNEL



THREE-WAY BRANCH. UNLINED FIELD CHANNEL



TURNOUT. LINED FIELD CHANNEL
TO UNLINED FARM CHANNEL



TURNOUT. UNLINED FIELD CHANNEL
TO UNLINED FARM CHANNEL

1 R.C CHECK. CLOSURE TILE NOT SHOWN.

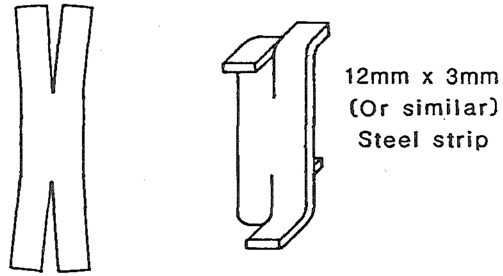
2 STANDARD OUTLET BLOCK.

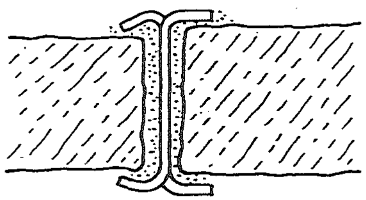
3 HEADWALL FOR OUTLET BLOCK.

STEEL RETAINING CLIP FOR STONE SLAB LININGS OF WATERCOURSES

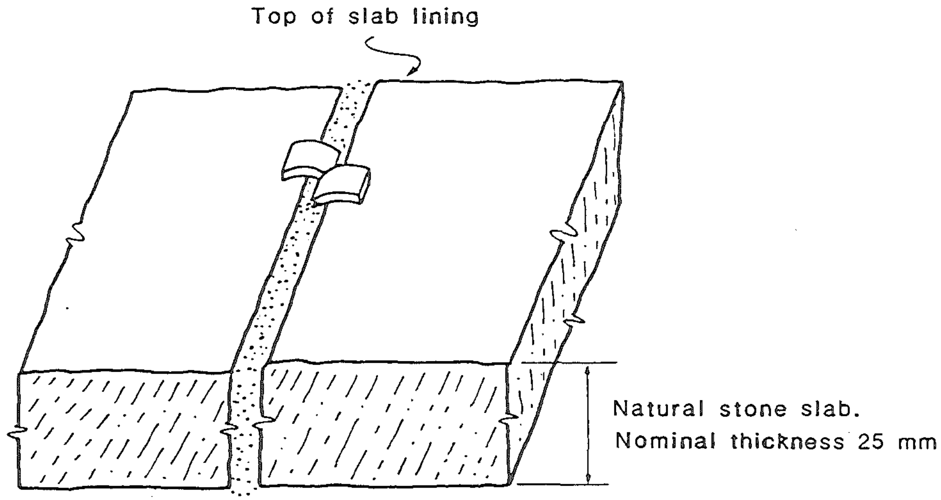
(Prevents removal and theft of slabs)

CUT WITH COLD CHISEL
OR METAL SHEARS AND BEND AS SHOWN



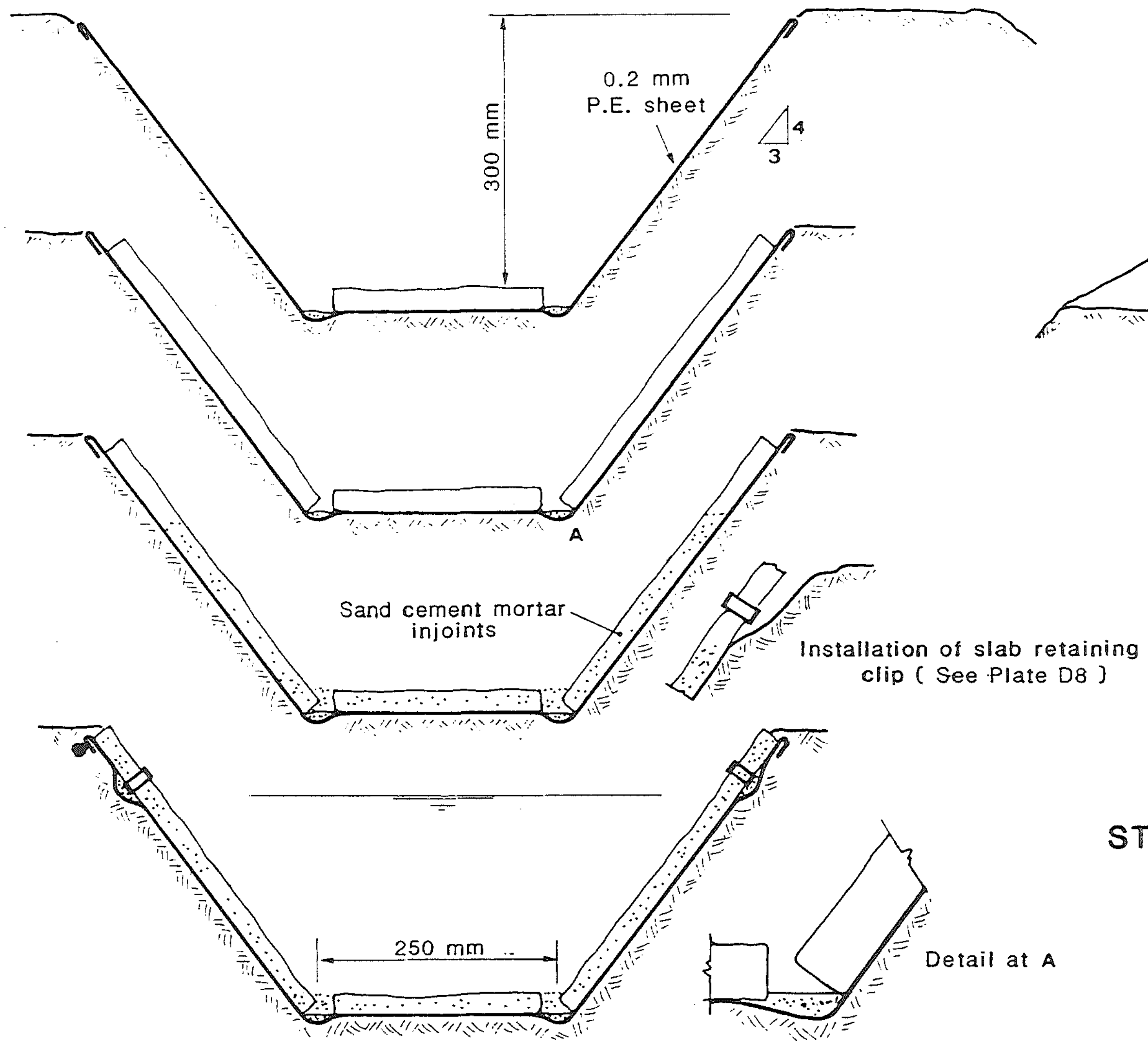


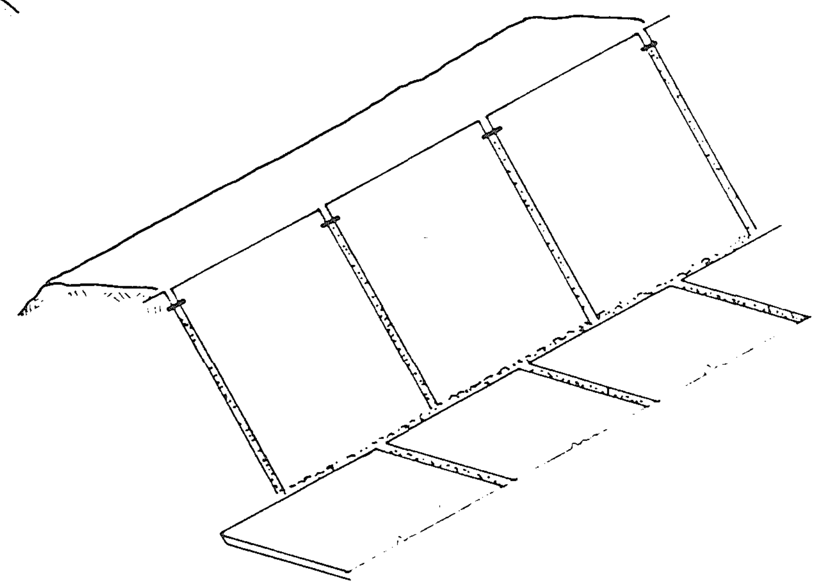
SECTIONAL VIEW OF
SLABS AND RETAINING CLIP



RETAINING CLIP IN PLACE.
VIEWED FROM INSIDE OF CHANNEL

PLATE 8





STONE SLAB LINING FOR WATERCOURSE

Steps in installation

DDC1085-718

M-56
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