



➔  **Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)**

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## **Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)**

### **Chapter 7 - Canal systems for smallholder irrigation**

#### **Introduction and definitions**

**It is often stated that all problems with the small irrigator would vanish if he were simply given a regular, dependable, timely supply of water. Unfortunately the monsoon, principal source of water in the region under discussion, is neither entirely dependable nor always timely. Irrigation is conditioned by supply as well as by demand, and conflict between the two is to some extent unavoidable.**

**Major irrigation systems can be designed and operated with a formal supply system extending down to the individual farm, "formal" implying construction, operation and maintenance by government agency (e.g. departmentally). Alternatively, the formal system may stop some distance away from the individual farm, delivering to an area in which the farmers manage the distribution of water themselves. This may be as little as 30 or 40 ha, as much as 100 ha or more. However, due to the inefficiency of water distribution within that area, encountered in many such systems, the trend over the last two decades has been to reduce its size and to extend departmental activities to the design and, in some cases, the construction of the distribution system within it. Maintenance and**

**operation of that system remain the responsibility of the group of farmers which it serves. For purposes of this discussion, the area served by the outlet from the formal supply system is referred to as the outlet command, and the distribution system within it is referred to as the tertiary system.**

**A number of factors have led to efforts in recent years to increase the role of cultivator groups in management of the lower end of the system. One is the major cost of staffing an organization capable of operating a formal system extending down to the individual farm, and the difficulty of recovering such cost from cultivators. Another is the conviction that the cultivators themselves are better capable of managing the system at that level. Finally, much faith is placed on the thesis that the tertiary system will be better maintained if the cultivators have full control of it. Group operation of the lower end of the system is not without its problems (discussed later) but in a smallholder situation, particularly in the absence of land consolidation, it is believed to be the practical solution. The remainder of this discussion is in that context.**

**There are two types of variable which must be considered in the design and operation of an irrigation system. The first is imposed by natural conditions, including variations in availability of water to the canal system, the occurrence and amount of rainfall on the project area, and variations in suitability of lands within the area for cultivation of particular types of crop. The second type of variable is inherent in the freedom of choice of the individual farmer, or group of farmers, regarding crops to be grown and hence the pattern of irrigation requirements. Such choices are often determined by changing market conditions for various crops. The site variables must be accommodated; the cultivator-related variables may be subject to some degree of regulation by project authority**

**(Frederick 1993, Hoffman 1990).**

**The design of an irrigation system sets out to optimize the use of the water resource, taking into account the variable nature of the supply and demand as discussed above. Two basic issues are the degree of sophistication acceptable in the design and operation of the system, and the degree of freedom of choice in cropping pattern which is to be left to the cultivator.**

**A system capable of carrying optimization to the ultimate degree would be very sophisticated indeed, and probably inappropriate to the region under discussion. Limits in the practical level of technology in design and operation are imposed by several factors. These include cost in relation to productivity (cost effectiveness), financial resources available, the ability of the agency concerned to-construct, maintain, and operate the facilities including funding of operation and maintenance, and finally the prospective attitude of cultivators to the type of operation proposed. The latter can be a key factor. If an operation, although entirely logical from the system viewpoint, meets with cultivator disfavor it is likely to be subverted by interference with control structures, or construction of unofficial checks or outlets ("destructive self-help" as one commentator puts it). Vulnerability of structures to misoperation and susceptibility to theft of components may be a very real constraint on the degree of sophistication and on the practical limits of efficient water use which can be aimed at in a particular project situation.**

**The question of freedom of choice of crop and consequently of timing of irrigation supply, versus project-wide standardization, is a fundamental one in the design of an irrigation system. Where soils and topography are uniform throughout a**

**project area, and groundwater can be utilized by the individual cultivator who has special water needs, standardization of canal supply based upon the requirements of the most commonly grown crops is generally practiced in South Asia. On the other hand, where soils and topographic conditions vary to an extent compelling radically different classes of crop to be grown in different areas of a project, canal delivery tailored to these specific areas is desirable. However, where the variations in soil and topographic conditions commonly occur within small areas, as can be the case in some topographic situations, tailoring delivery to such areas becomes difficult.**

**Aside from situations in which site conditions impose variations in class of crop, there is the more general case of the cultivator who wishes to depart from the project norm and to grow specialty crops requiring special water scheduling, but is in an area where groundwater is not available. This brings up two questions: should the canal delivery system recognize such needs and should such diversification be encouraged? and what are the practical limits to meeting such demands?**

**Terms used in referring to the successive orders of the canal system differ regionally, causing some confusion in the literature. The following alternatives are in common use:**

<b>Irrigation Sub-System Conveyance System</b>	<b>Alternative Terms Primary canal and branches Secondary canal and branches</b>	<b>Main canal and branches Distributary canal and branches</b>
	<b>Sub-secondary</b>	<b>Minor (or tertiary)</b>

Distribution system commonly serving	Tertiary (or watercourse)	Watercourse (or field channel)
30 to 40 ha	Quaternary (or field channel)	
Within the individual holding	Farm Channel	Farm Channel

**The capacity or area served by a particular order of conveyance canal varies widely with the size of the scheme. The area served by a tertiary (or watercourse), however, is more specifically defined, as discussed later. The terms employed herein are primary, secondary, sub-secondary, tertiary or watercourse, and field channel.**

### **Designing for variable supply**

**Canal supply from a monsoon-fed source is inherently variable. A regulating storage, if such is available, can improve the situation considerably, but two basic questions remain. First, what proportion of the historic mean flow should the system be designed for, and second, how should it be operated in periods of less than the design flow. Greater system capacity means greater total utilization of water, but it also means more frequent operation at less than capacity, and more frequent deficiencies in supply to the cultivator. Both cause problems (Berkoff, 1987 and 1990).**

**Rainfall, in a monsoonal area, is also highly variable. Here again, a basic question is the proportion of the historic mean which should be taken into account in calculating irrigation needs. Where rainfall is substantial, but nevertheless**

**insufficient to provide fully for paddy requirements, canal supply is complementary to rainfall. If too conservative a view of rainfall is taken, the necessary canal duty will be overestimated and the area which can be served by the available canal supply will be restricted. Conversely if rainfall projections are optimistic and canal duty is underestimated, periods in which rainfall deficiency cannot be entirely compensated by canal supply will occur too frequently. That some periods of deficiency in rainfall plus canal supply will occur is inevitable, particularly where rainfall in the catchment supplying the canal system and that in the irrigation area are subject to the same climatic conditions, hence when there is a rainfall deficiency in the project area there is also deficiency in the catchment. The relationship between the onset of monsoon rains in the supply catchment and in the project area is especially sensitive where canal supply is relied upon to provide a proportion of the water needs for puddling and transplanting of rice in the critical initial month of the monsoon. This may be a key factor determining the practicability of double-cropping of paddy versus single cropping, and the timing of planting of follow-on dry season crops.**

**The occurrence of deficiency in monsoon rainfall in rainfed paddy areas is a situation entirely familiar to cultivators. Up to a point such deficiencies can be accommodated. As previously noted, water consumption by paddy can be reduced by up to 20% by reverting from continuous flooding to intermittent flooding, without major loss of production, although at the expense of greater labor in weed control. Much paddy is traditionally grown in this fashion in rainfed areas. However, on introduction of canal supply, cultivators generally assume that problems of deficiency are in the past, and when that proves to be not entirely the case unofficial diversions and tampering with control structures, also headend versus tailend problems, must be anticipated. No solution to this problem has yet**



**been found other than more intensive operational supervision, or hopefully more effective farmer-group management than has yet been generally achieved.**

**Where monsoon rainfall is inadequate for rainfed paddy, and other (dry-foot) crops are traditionally grown, there is a possibility that the advent of canal supply may bring about a radical change to monsoon-season paddy, resulting in substantial demand for water. However, assumptions that such a change will occur must be viewed with caution. For example, a clayloam soil believed to be suited to paddy under irrigation actually proved to be quite unsuitable for relatively obscure reasons (phosphorus deficiency under the conditions of wet-land paddy, and extremely sticky nature when wet). A design incorporating the use of the large "surplus" supply of water available in the monsoon season should begin with a careful analysis of agronomic factors which may influence such use. Either monsoon-season or dry-season irrigation may be found to be the determining factor in arriving at the capacity of the canal system. But in either case there will be periods in which supply or demand are considerably less than system capacity. The question of how the system is to be operated under such circumstances strongly influences its design, particularly the nature of the hydraulic controls. Consequently, planning of system operation must go hand-in-hand with, or precede, detailed engineering design.**

**Much ingenuity has been exercised in meeting periods of "scarcity" of supply, in both public and farmer-operated systems. Some measures taken include proportionate reduction in rate of supply or in frequency of supply throughout the service area or a selective sacrificial approach in which supply to a portion of the area is foregone for the whole season. Another measure is a system in which each secondary has a rotating schedule of weekly priorities (first, second, and third)**

**which determines those secondaries which will have supply withheld in a particular week if supply to the system is in deficit. The latter system (traditional in north-western India) distributes adversity on a mathematically equitable basis and is easily understood by all concerned. However, it does not necessarily result in maximum production. An effort is being made to introduce other factors into the scheduling of priorities, but whether this more sophisticated (computer assisted) approach will be acceptable to cultivators is yet to be seen.**

**The most effective handling of "scarcity" is probably that observed in a village "tank" system, with a small reservoir and a service area of a few hundred hectares. During a period of deficiency in which the reservoir only partially fills, a village meeting may be convened, taking place on the slopes of the dam from which both the contents of the reservoir and the whole of the service area are visible. Questions of whether to reduce the rate of supply or to delete supply to a portion of the service area for the season, and whether to use the remaining storage to save the standing crop or to hold it over for the equally important purpose of pre-monsoon irrigation in the next year, are discussed, and decisions are made by consensus. A further level of ingenuity is displayed in some village schemes (e.g. the bethma system in Sri Lanka) in which cultivators with holdings in the lower end of the system are moved to the upper end during periods of scarcity, and share in cultivation of that area for the duration of the season, during which time irrigation supply is confined to that upper area.**

**However, expedients available to a small village scheme are not generally available to a major public system, where the cultivator is only aware of what goes on in the canal serving his area. Generally, deficiency in supply in a major system results in illegal operation of control structures and illegal diversions. The**

**net effect is that upstream irrigators secure their supply, and the deficiency is passed on to "tailenders".**

**The options available for distribution of water in times of reduced supply or demand are the following:**

- (a) To reduce the rate of flow in all channels;**
- (b) To reduce the rate of flow in the primary canal (still maintaining continuous flow in it) and to supply full flow in rotation to secondaries and their tertiaries;**
- (c) To reduce the rate of flow in both primary and secondary canals, and to supply full flow in rotation to tertiaries;**
- (d) Similar to (b) but instead of a fixed rotation to secondaries, priorities are rotated (the north-western Indian system discussed above);**
- (e) To delete supply to portions of the service area for the entire season;**
- (f) To supply on "limited demand".**

**The relative merits of these alternative systems is discussed subsequently.**

**Varying demand within the service area**

**As noted earlier, changing market conditions can bring about radical changes from the cropping pattern as conceived at the time of project formulation. The**

**possibility of such changes should be taken into account in project design, with particular regard to determining desirable canal capacities.**

**Variations in cropping pattern and in irrigation requirements within the service area may be due to soil conditions, for instance the occurrence of valley-bottom lands with heavy soils and poor drainage in one portion of a project and uplands with very light shallow soils in another. A uniform project-wide cropping pattern would not be appropriate in such circumstances nor would a uniform schedule of water deliveries, with the cultivator being left to decide on its use, as crops appropriate to the lowland area are likely to require water at seasonally different times from crops in the upland area. Where the different soil situations occur in homogenous areas of substantial size, virtually as major sub-divisions of the project, independent branch canal systems with independent scheduling may be the logical solution.**

**A more difficult situation is encountered when substantially different soil types occur within a small area. An example is in gently rolling uplands dissected at frequent intervals by shallow valleys. Small streams meander between alluvial terraces in each valley bottom. The upland soils are free-draining and suited to a variety of non-paddy crops.**

**The valley-bottom lands are in heavy clay soils, poorly drained and slow to dry out after the monsoon season. They are suited to paddy only, but offer the possibility of double cropping of paddy. The differentiation of soil types is on a small scale, with typically one tertiary command (30 to 50 ha) in one soil type and the neighboring command frequently in the other. This is a common situation in the service areas of small (50 to 100 ha) village "tank" schemes. The area includes**

**valley-slopes in irrigated upland crops, and in the valley bottom a narrow strip of paddy. The same supply canal which serves the upland crops also serves the paddy area, via downslope branches. Regulation of supply to upland or to lowland areas is not a problem in the closely-knit social structure of the small village. In the context of a larger public system, however, the same topographic situation, repeated throughout the project area, does pose a problem. To cater to the irrigation requirements of the two soil types (particularly differences in seasonal timing) is technically possible, but requires more intensive operational staffing than is normally provided and a more elaborate system of hydraulic controls.**

**The diversity in type of crop and in irrigation scheduling discussed above is imposed by soil conditions. A more general question is whether simply the preferences of the individual cultivator or group of cultivators should be accommodated in scheduling water deliveries. This is the question of the specialty crop. It may be vegetables, sugar-cane, bananas, fruit-crops, pond fish culture, etc. in an area otherwise devoted to regular field crops. With basic food-grains now reaching the stage of overproduction in some regions of S. Asia, there is much emphasis on diversification, particularly higher-value crops. This has become a matter of urgency in some areas.**

**The availability of good quality groundwater at depths accessible to the small cultivator may be the solution to the problem of irrigation of specialty crops within a canal system command. In areas of hard-rock substructure, however, the ground water yield may be small, although augmented by seepage from the irrigated area, and large-diameter dug-wells may be needed. Although expensive, they have the virtue of storage capacity and may function virtually as small farm-level short-term pondages, being filled in part by rotational supply from the canal**

## **system.**

**Larger lateral or terminal pondages are also attractive conceptually, insulating cultivators from the time constraints of rotational canal supply. However, in spite of considerable efforts to incorporate such pondages in some recently constructed schemes, sites which can be filled by gravity from the canal system and which can be drawn off by gravity have proved difficult to find. The addition of pumping could facilitate location of sites, but pondages are not expected to be a generally-applicable feature of irrigation in the region under discussion. Where small tank schemes already exist within an area about to come under canal supply they can furnish the desired storage. In some cases the function of the primary canal is in fact solely to supply existing tanks, and the scheme has no distribution system of its own. Alternatively, there may be a combination of new service areas supplied by the canal system and existing service areas served by tanks with supplemental canal supply.**

**Lateral and terminal pondages are, however, the exception rather than the rule, and in areas of hard-rock substructure the proportion of a command which can be irrigated from dug-wells, although important, is relatively small. This leaves the question of how deliveries from the canal system itself can best be adapted to serve areas of radically different soil types occurring throughout the project command, or the needs of diversification from the standard project-wide cropping pattern.**

**In this regard, it is noted that the situation in an irrigation project serving smallholders is very different from that in Western countries, where a project is likely to serve much larger holdings or larger Water Districts. In the latter case,**

**supply of water in response to day-to-day "limited demand" is feasible. The request for water can be met provided it does not exceed the limits of conveyance capacity or the availability of water, taking into account concurrent requests from other irrigators. Technicalities of canal operation are not usually a constraint. Designing for such "limited demand" operation incidentally requires incorporation of a diversity factor in sizing of canals. As the probability of all the irrigators served by a lower-order canal requiring water at the same time is greater than in a higher-order canal with larger number of irrigators, in determining canal capacities a factor is applied to the peak water duty (flow per unit of area served) varying from unity for the main canal, and progressively increasing to as much as two or more for the lowest order canals. This procedure is not followed in those smallholder systems which are designed on the basis of a uniform cropping pattern. In this case the water duty is taken as constant throughout the system, subject only to conveyance losses which, in fact, marginally reduce the duty towards the lower end of the system. However, where a degree of "limited demand" capability is to be incorporated in a smallholder system the application of a diversity factor in determining canal capacities may be necessary.**

### **Allocation of water and establishing water charges**

**Equity in allocation of water may or may not be a consideration in the design of smallholder irrigation. In some schemes, allocation in proportion to the area of holding is strictly followed, or at least it is aimed at. In others, each cultivator makes an application for water to irrigate a nominated area of a particular crop. Each application is viewed along with all other applications, and with such modifications as circumstances may indicate it is finally "sanctioned". The irrigation agency then endeavors to make the necessary water available to meet**

**that sanction by incorporating the cultivator's holding in an appropriate rotational schedule. This is the "rigid shejpali" system practiced in central India. In sanctioning, restrictions on the proportion of certain crops, such as sugar-cane, are placed more for reasons of watertable control than for reasons of equity in water distribution.**

**Where water is allocated in proportion to area of holding it is in fact an entitlement, rather than an amount of water, which is allocated. In the original N.W. Indian system the cultivator was obliged to take his share of water when his turn came (the "warabandi" system). This presented no problem to the cultivator in that area, as the amount allocated was always less than he could use, i.e. water was always needed. The present concept is a broader one. Among the group of cultivators served by a tertiary (watercourse) each has a basic entitlement but he is not obliged to use it and he can transfer its use to other members of the group by informal adjustment of the rotational schedule.**

**Where water is distributed on the basis of uniform entitlement per unit of area of holding, water charges are based on a per-hectare per season basis. Where distribution is on the basis of sanctioned areas of particular crops water charges are usually based on area and type of crop. The latter charges taken into account the relative amount of water which the type of crop uses, and the economic returns from it.**

**Charging on the basis of actual volume of water used, usually regarded as the ideal system, is not generally practiced at the level of the individual cultivator or of the tertiary command in the South Asian region. This is due to the practical difficulty of maintaining recording equipment at that level. However, it is being**



**employed in some cases where water is supplied to a cooperative, particularly for sugar-cane production. In tubewell systems, direct or indirect volumetric charging for water is commonly practiced.**

## **Capacity of primary and secondary canals and size of irrigation area**

**In determining the capacity of the primary canal, two factors are relevant:**

- (a) The availability of water (rate of flow) at the primary canal head, modified by storage if any, month by month throughout the year**
- (b) The pattern of varying demand for irrigation corresponding to the proposed composite cropping pattern, throughout the year.**

**The two factors are related, in that the cropping pattern may be designed to make best use of the seasonally varying irrigation supply. Conversely the operation of the storage reservoir, if any, will be designed around the varying seasonal irrigation needs of the selected cropping pattern.**

**With regard to the second factor, in designing the system it is convenient to work with a hypothetical area of 100 ha under cultivation with the proposed crop mix and with 100% irrigated crop intensity (also hypothetical) in the season of maximum irrigation intensity. The irrigation demand for this area is estimated at weekly intervals and plotted throughout the year. The 100 ha area is then scaled up progressively until the plot of irrigation demand touches the monthly plot of flow available. The corresponding peak annual demand for that scaled-up area gives the desired nominal maximum design rate of supply at the primary canal head. If the irrigation system were based on a design rate of flow smaller than that**

**value, the available supply would only be partially utilized throughout the year. If on the other hand, the system were to be based on a design rate of flow greater than that value, there would be a deficit in part of the year.**

**As discussed above, cropping pattern and reservoir operation may be varied to optimize water use, for instance to maximize water use in the high-flow season, or to minimize demand in the low-flow season. Hence, the procedure described is part of a trial and error process in project design.**

**It is emphasized that the desirable maximum design rate of flow at primary canal head determined above is not necessarily the same as the canal capacity. Canal capacity may be made greater than the nominal maximum design rate of flow for a number of reasons, including provision for possible future changes in cropping pattern (particularly in reservoir-controlled systems) or to accommodate unsteady flow in the canal. It is, however, a key parameter in the design of the remainder of the system.**

**So far no reference has been made to size of irrigation area or to actual irrigation intensity. The hypothetical 100 ha irrigated at an assumed 100% intensity in the peak season has been scaled up until demand matches the available flow in the critical period. The area so derived by this scaling-up process is the net service area which could be supplied at 100% intensity during that period. However, the area actually served could be made considerably greater, for social or other reasons. In this case, the irrigation intensity would be correspondingly smaller. It is noted that reducing the irrigation intensity through increasing the size of the service area does not change the design rate of flow or canal capacity at canal head.- It does, however, affect the figure commonly referred to as the canal**

**"duty", which is simply the design maximum flow per hectare of area served by the system. If the peak design irrigation intensity is reduced by 20% by increasing the size of the service area the canal duty is similarly reduced. Provided that the cropping pattern is uniform, the canal duty in the primary and secondary canal system is uniform throughout (adjusted for losses), and the design flow at any point on a canal is proportional to the area commanded by that point on the canal. An exception is noted when a secondary is designed to operate rotationally, half the time on and half the time off, even in the season of peak delivery. Such operation is the exception but it is practiced in some systems with long unlined secondaries, in order to minimize conveyance losses. In such circumstances, the canal duty has to be doubled if the same seasonal delivery of water per unit of area is to be achieved, as with a system based on continuous operation in the peak period.**

**The same canal duty, adjusted for conveyance losses, is also applied at the head of the tertiary, provided that the cropping pattern is uniform. However, what distinguishes a tertiary from the higher-order canals is the fact that the design flow remains constant throughout the tertiary command. For reasons discussed in the next section, it does not reduce as the area served reduces, toward the outer margin of the tertiary command.**

## **Distribution at the tertiary level**

### **Background**

**A tertiary channel or watercourse commonly serves 30 to 40 ha, in some cases up to 100 ha. In a major public scheme operation above the tertiary, including the**

**intake to the tertiary, is usually the province of the Irrigation Department. Operation within the tertiary command is commonly (and preferably) carried out by the irrigators which it serves.**

**The design of the distribution system within the tertiary command is influenced by the size of holdings (the term holding is used in the sense of a contiguous area farmed as a unit), as well as by the type of crop being grown, particularly the extent of paddy. The following discussion presents the three cases of cultivation of non-paddy crops, paddy as the primary crop, and mixed-cropping.**

### **Tertiary system design for non-paddy crops**

**Where holdings are relatively large (5 to 10 ha) the tertiary and its branches provide an outlet (usually a single outlet) to each holding. Within the holding, water distribution is by farm channel. Where holdings are small, typically less than one-half hectare, a further division of the canal hierarchy may be introduced. This is the quaternary or field channel. In this situation, the tertiary command is divided into sub-units of 4 or 5 ha, each provided with an outlet from the tertiary. Within the sub-unit, field channels carry the distribution down to the individual holding. There may be four or five holdings or as many as twenty or thirty in a typical sub-unit. It is noted that in the situation being discussed property boundaries are irregular. In the contrasting situation in which land consolidation has been carried out, or in new sub-division of lands for settlement purposes, boundaries may be near-rectangular and oriented with regard to land slope. In that case, channel layout within the tertiary command is simplified and the small holding may be served directly from the tertiary, without intervening field channels.**

**Hydraulically, tertiaries and field channels, are simply successive elements of a continuous branching system extending from the tertiary head down to the turn-out to each holding. Channel capacity, in most cases, is the same throughout. However, the field channel is closer to the farmer than the tertiary and may differ in the need for, or absence of, right-of-way procurement and in the extent of farmer participation in construction. Furthermore, tertiaries may be partly or wholly lined, but rarely are field channels.**

**As noted above, channel capacity is usually constant throughout the tertiary/field channel system. It does not reduce from tertiary to field channel. This reflects the important design philosophy that a key factor in obtaining satisfactory irrigation efficiency with non paddy crops is an adequate stream size at the field level. This desirable rate of flow at the point of delivery to the holding depends on the size of the holding, soil infiltration rates, ground slope, and other factors, but is generally in the range 30 to 60 liters/sec (about 1-2 ft<sup>3</sup>/sec). A rate that is too low will result in excessive seepage from field channels and poor field efficiency, while a rate that is too high will lead to water management problems for the farmer.**

**The tertiary is designed to supply water at this selected rate. In fact, this may be regarded as the definition of a tertiary. A corollary is that the flow in the tertiary should not be further divided enroute to the point of delivery to the holding, i.e. one farmer at a time should take the full flow of the tertiary/field channel system. This situation is in contrast to that in many older systems in which any number of cultivators may divert from the watercourse, each taking an indeterminate amount of flow, generally excessively small or nil at the outer perimeter of the tertiary command. The arrangement in which one farmer at a time takes water from the tertiary/field channel system, if complied with, assures adequate delivery stream**

**size at all points. It also permits control of the respective amounts of water taken by each cultivator by fixing the duration of his irrigation within the rotational supply period.**

**The system described has much merit and is a key provision in World Bank assisted irrigation development in the Indian sub-continent over the last fifteen years. It has its origin much earlier in N.W. India. However, it is not universally practiced elsewhere in South Asia, and it has encountered operational problems in some areas in India, particularly where paddy is an important crop component.**

**A variant employed elsewhere involves supplying two or three holdings simultaneously from the tertiary, the latter being of correspondingly greater capacity and serving a greater area of command than with the single turn-out system. Supplying several holdings simultaneously in this manner poses the problem of how to ensure that each turnout takes its proper share of the flow the tertiary/field channel system. With appropriate control structures, this could be achieved, technically, but it would require a regulated outlet (not simply a fixed orifice) at each turnout, capable of delivering the desired flow under conditions of varying head in the channel. As there are commonly thirty or forty or more holdings in a tertiary command, each with turnout, provision of such regulated outlets would be a substantial cost item and a major problem of operation and maintenance. In fact, where diversion to more than one holding at a time is practiced, the division of the flow between turnouts is usually on a judgement basis by the cultivators, without the use of formal regulating structures. The one-turnout-at-a-time system avoids this problem, the rate of flow being controlled at the intake to the tertiary only. The turnouts to each holding are operated simply on an on/off basis, each in turn taking the whole flow of the tertiary/field channel**

## **system.**

**While conceptually simple, the latter system does depend for its success on the cooperation, or restraint, of the cultivators. Out-of-turn diversions can defeat its operation, and Departmental supervision at the level of the tertiary command is virtually infeasible. Control must be by the cultivator group.**

**Two factors enter into determination of the size of the area commanded by a tertiary. One is the desirable rate of flow at the point of delivery to a holding (the farm stream). As previously discussed this should be in the range of some 30 to 60 liters/sec. The other factor is the canal duty (design maximum flow per unit of area served). The duty applies from primary canal head down to the outlet to the tertiary, subject only to adjustment for losses enroute and provided that the tertiaries are designed to run continuously during periods of peak demand and that water allocation is uniform throughout the project area. In such circumstances, the size of area commanded by a tertiary is obtained simply by dividing the water duty into the farm stream. Thus, a water duty of 1.2 liters/sec/ha and an adopted farm stream of 30 liters/sec would give a service area of  $30/1.2$  or 25 ha. In actual practice, the size of service area is likely to be influenced by topographic features and location of property boundaries, and the tertiary capacity may have to be adjusted accordingly, although still within a small range either side of the desirable value.**

**A common problem with tertiary channels is excessive seepage losses and poor service to tailenders. This can be encountered when the irrigation intensity is low, with correspondingly low water duty, and the area is in soils with a high infiltration rate. The low duty results in a relatively large area of tertiary command**

**with correspondingly great length of tertiary/field channel in relation to its small stream size. In high infiltration rate soils this may result in excessive proportionate seepage losses. Adopting a farm stream at the higher end of the practical range for efficient water management can assist, also lining of the main stem of the tertiary. Other alternative courses are to design the tertiary system for rotational operation (50 % on, 50 % off) even in the season of peak supply, which doubles the duty and halves the size of tertiary command, or to design the system for supply to two or three holdings simultaneously rather than to one only. This doubles or triples the required capacity of the tertiary and reduces proportionate seepage losses. However, this course loses the operational advantages of single point delivery previously discussed.**

**Appropriate layout of the tertiary/field channel system is essential to preserving cultivator harmony. Although the channel network provides an important service, it nevertheless occupies a significant amount of agricultural land for which adequate compensation may or may not be paid, and it can greatly obstruct access to farm and field. Correct siting of the tertiary intake and of turnouts to individual holdings has considerable bearing on its ability to command distant fields. Provision of channel crossings on traditional village access routes and access over channels to farms are also items of vital interest to cultivators in the area Current policy of investment institutions is to favor maximum participation of cultivators in all phases of layout of the tertiary/field channel system, and if possible also in its construction. Such participation is essential if cultivators are expected to operate and maintain the system.**

**Although technically straightforward, tertiary system layout requires detailed topographic and cadastral (land ownership) data Most errors in layout and**



**cultivator complaints stem from the use of inaccurate or insufficiently detailed contour plans. Verification of layouts by field survey, particularly levelling, is essential, as is flagging of alignments and turnouts prior to construction to ensure that cultivators are in agreement with their location.**

**The responsibility of the agency constructing the project is usually considered as ceasing at the boundary of the holding. Thereafter, the farmer takes care of water distribution. It is nevertheless emphasized that in irregular topography, or in slopes of 2-3 % or greater, water distribution within a holding as small as one or two hectares can pose problems which a cultivator cannot be expected to overcome without guidance. Erosion of down-slope farm channels resulting in loss of command of fields is a typical problem, requiring some form of control structure, however primitive. In such circumstances, advice should be provided regarding water distribution and associated land shaping. However, water distribution at this level is usually regarded as outside the scope (or beneath the professional dignity) of conventional irrigation engineering, nor is it covered by agricultural extension. Consequently, such assistance is conspicuously absent in most cases.**

### **Tertiary system design for areas primarily under paddy**

**The previous discussion has been with regard to irrigation of non-paddy or "irrigated dry" crops. Where paddy is the principal irrigated crop, other crops being incidental, water distribution within the tertiary command can be very different from that described above. In the case of irrigated dry crops, a critical factor is field efficiency, including efficiency of distribution within the field by farm channel or furrow. Hence, there is an emphasis on adequate size of delivery**

**stream. With paddy, however, the field is flooded and efficiency of conveyance or distribution within the field is not a factor. During the growing season a small continuous flow to the ponded field can be perfectly satisfactory. During cultivation and puddling, on the other hand, a substantial supply of water is required for a short period.**

**Water needs for wet-land paddy have been discussed earlier. Cultivation and water distribution practices vary widely. In many wet-tropic areas the traditional approach has been to supply large blocks (1000 ha or more) by field-to-field flow. Cultivation and puddling progress from upper to lower portions of the area, the whole process taking a month or more. Irrigation subsequent to transplanting is also field-to-field, requiring virtually no formal distribution (tertiary system) within this large area**

**In contrast, paddy cultivation in other areas is on the basis of the individual holding. A cultivator may have regular employment outside the farm and may wish to have cultivation and transplanting completed in as short a period as possible (two or three days), often by contractor, and largely independent of the activities of his neighbors. Further, during the growing period a cultivator may wish to withhold irrigation from his fields at intervals to optimize efficiency of fertilizer application, either coordinating this activity with his immediate neighbors or independently. This situation calls for a network of delivery channels capable of controlled supply to relatively small units of area This may also be necessary where irregular topography precludes full command of large blocks by purely field-to-field delivery.**

**However, tertiary channels within an area under paddy have their problems, and**

**may be shortlived. The habit of encroaching on channels during puddling (in order to maximize planted area) often leads to collapse of the channel bank. The channel is lost, and the system reverts to field-to-field distribution in large units. In fact, if paddy cultivators have a tertiary network imposed upon them, rather than requesting it, eventual destruction of the network is highly probable.**

**Nevertheless, with widespread adoption of High Yielding Varieties and associated increased fertilizer application, as well as increased double-cropping through the use of short-duration varieties, finer-tuning of paddy irrigation is increasingly desirable. A compromise employing a limited tertiary system delivering to sub-units of five to ten hectares, within which distribution is field-to-field, may be the solution. Whatever system is adopted, however, it must have the blessing of the cultivators concerned, and must be regarded as permanent. Where gradients permit, the use of buried-pipe tertiaries delivering to valved outlets serving each sub-unit could avoid much of the problem of open-channel distribution in paddy areas.**

**In a predominantly paddy area, determination of the maximum design flow in the primary canal, size of service area, and canal duty, follows the same procedure as previously described for irrigated-dry crops. However, estimation of water requirements for cultivation and puddling is likely to be contentious, being dependent on assumptions as to the amount and timing of early monsoon rainfall, the period over which land preparation and transplanting is likely to extend in the area as a whole (this may be four to six weeks), and the cultivation/puddling practices expected to be adopted by the cultivators. Duty at primary canal head, assuming 100% irrigation intensity in the peak season, is likely to be between 1.5 and 2.0 liters/sec/ha, with corresponding figures at tertiary intake (allowing for**

**losses enroute) in the range 1.2 to 1.5 liters/sec/ha The possible adoption of peak season irrigation intensities of less than 100% for reason of social equity was discussed earlier in connection with irrigated dry crops. Such a course is unlikely in areas primarily devoted to paddy, where cultivators traditionally expect the entire area to be under that crop, for at least one season. The desirable rate of delivery to the farm (the delivery stream) for paddy during the stage of cultivation and puddling is likely to be higher than for irrigated dry crops, probably in the range of 40 to 80 liters/sec, assuming delivery to one turnout at a time.**

**The appropriate size of tertiary command is derived from the duty at tertiary outlet and the size of farm stream adopted, as discussed for irrigated-dry crops. Thus, with a duty of 1.2 liters/sec/ha and a delivery stream of 40 liters/sec the nominal size of tertiary command would be  $40/1.2$  or 33 ha. With a duty of 1.5 liters/sec/ha and a delivery stream of 80 liters/sec it would be approximately 50 ha.**

**In areas wholly under paddy, cultivators may choose to practice rotational delivery only during the period of puddling and transplanting and during the growing season to supply all sub-units simultaneously with a smaller continuous flow, just sufficient to maintain inundation. However, when limited water supply precludes continuous flooding, periodic (weekly) inundation may become necessary, with full-now rotational supply to each subunit in turn.**

**The above discussion assumes delivery to one sub-unit at a time in periods of rotational supply. As discussed in connection with irrigation of non-paddy crops, it is also possible to design the tertiary system for simultaneous supply of the full delivery stream to two or three sub-units rather than to only one, consequently**

**doubling or tripling the required capacity of the tertiary channel and the area of tertiary command. The disadvantage is the need for installation and operation of regulating structures on the tertiary and the reduced level of control on the amount of flow taken at the sub-unit.**

### **Tertiary system design for mixed cropping**

**Paddy and non-paddy crops may be irrigated at the same time, or sequentially, with paddy being irrigated during the monsoon followed by other crops in the dry season. Where both types of crop occur within the same tertiary command, which is the general situation, operational and design problems are encountered. The operational difficulties stem from differences in the amount and in the timing of irrigation needs of the two crops. The design problem is that nonpaddy crops require a closer tertiary/field channel network than does paddy. With paddy, formal irrigation distribution may stop at the boundary of the sub-unit, with field-to-field flow thereafter. Non-paddy crops, however, require formal distribution, by tertiary and field channel, right down to the border of the field.**

**While paddy can be irrigated with a tertiary/field channel system designed for non-paddy crops there is a strong possibility that the field channels (within the sub-unit) will be destroyed by encroachment during cultivation for paddy and will have to be reconstructed prior to the followon non-paddy crop. In &et, cultivator practice, in some areas where wheat follows paddy, is to each year construct temporary field channels after harvesting paddy, before planting wheat. This can be quite effective if the length of the temporary channels is small. If longer, their delivery efficiency can be poor, particularly to tailend cultivators.**

**An effective compromise is to carry the permanent tertiary system down to relatively small subunits (2 to 4 ha), and to leave it to cultivators to construct temporary field channels within the sub-units each season. The alignment of the temporary channels and the rights of tailenders to conveyance of water via such channels should, however, be officially established.**

**In mixed cropping, the peak rate of supply may occur in the early monsoon season during puddling for paddy and may greatly exceed the available rate of supply or the demand during the subsequent dry-season. Furthermore, the desirable size of delivery stream during puddling may be considerably greater than that required for the dry-season non paddy crop. In such circumstances, there is a case for reducing the rate of diversion to each tertiary in the dry season. This can be achieved, with some approximation as to sharing between outlets, simply by reducing the flow and the level in the parent secondary canal. Alternatively, gated outlets to tertiaries may be provided and adjusted seasonally, although this departs from the operationally preferred course of fixed outlets. The use of a second outlet (usually simply a pipe) for supplemental diversion in the paddy season is practiced in some areas. However, employing either adjustable or supplemental outlets invites their misuse in the dry season.**

### **Layout of tertiary channels**

**The importance of involving cultivators in the layout and construction of tertiary channels has been referred to earlier. An issue which frequently arises in areas of irregular field boundaries or irregular topography is the extent to which tertiary alignment should follow boundaries or be routed more directly, crossing properties where necessary to do so. The latter course minimizes length and cost**

**of channel. However, it maximizes interruption to access for cultivation by bisecting fields and for the smallholder may result in disproportionate loss of cultivated area. Furthermore, in many cases compensation is not paid for right-of-way for tertiaries, the channels being regarded as communal property. Following property boundaries, although inconvenient from the layout viewpoint, does come close to equitable contribution of land for tertiary construction. However, routing the tertiary along boundaries is not without problems, particularly where there is considerable difference in elevation between fields lying on either side of the boundary, as is commonly the case in areas already terraced for rainfed cropping.**

**Determination of size of tertiary command and its division into smaller sub-units have already been discussed. While this procedure is conceptually simple, some site situations can make implementation difficult and may require departure from the idealized design. A case in point is supply to the long narrow strip of command frequently encountered between a primary and a secondary canal in its upper reaches. A tertiary channel serving, for instance, 30 ha in such a location could be several kilometers in length, running generally along the top of the primary canal embankment. In some situations, this can be impractical for a number of site-specific reasons. One expedient is to use a number of "direct" outlets, each taking off from the main canal and serving an area of a few hectares. While solving the problem in one sense, this arrangement requires that the direct outlets be independently operated (rotated), otherwise they would run continuously with the primary canal, taking an excessive amount of water. There is no entirely satisfactory solution to this situation.**

**A further problem is encountered in irregular topography where a secondary canal runs down a narrow spur, with the area to be irrigated lying on the slopes on**

**either side. Conventional layout would require relatively long tertiaries running parallel to and on either side of the secondary. However, the crest of the spur may not be sufficiently wide to accommodate all three channels if they are of regular trapezoidal section. One option is to omit the tertiaries and use direct outlets on the secondary, each serving an area of a few hectares. However, such outlets would require independent rotational operation, as the capacity (size of delivery stream) would be excessively small if scaled down commensurate with the small size of the area served so that they could be run continuously with the secondary. A second option has both secondary and parallel tertiaries. But in order to accommodate all three on the narrow crest of the spur, a rectangular composite flume section is used (concrete or brick) incorporating all three channels. This avoids the separate operation of outlets required in the first option. Choice between the two is a trade off between construction cost and operational simplicity.**

**A further example of conflict between technical and operational factors in tertiary system design involves the number of delivery points (turnouts) to a holding. To facilitate adherence to the rotational delivery schedule within the tertiary command, it is usual to observe the convention of a single turnout from the tertiary or field channel to each holding. Indeed this is very strictly enforced in some areas. However, there are site situations which strongly indicate otherwise. A case in point is a sandy soil with very high seepage losses in unlined channels. The tertiary is lined, but farm channels are not. A tertiary parallels the boundary of a holding of several hectares. The single turn-out rule would require a farm channel (unlined) to parallel the lined tertiary for several hundred meters, supplying down-slope branches. However, seepage losses in the farm channel would be high. The alternative would be to provide a second turnout from the**



**lined tertiary at about half-way down the length of the boundary, thereby much reducing seepage losses when supplying the lower end of the holding. However, the existence of two turnouts to the holding, although intended to be operated as alternates, invites the possibility of their being operated together, doubling the rate of diversion to the holding and infringing upon the rotational- schedule. This again is a case of conflict between technical desirability and simplicity of operational control.**

**Finally, there is the question of possible use of multiple siphon tubes for delivery from tertiary/field channel to the holding. Such plastic siphon tubes (about 5 cm diameter) can be used in groups of five or more, functioning in effect as a portable turn-out or separately supplying individual furrows directly from the tertiary, thereby eliminating the farm channel. This can be attractive in certain situations and is widely practiced in Western irrigation. However, the presence of large numbers of siphon tubes in a smallholder situation would be likely to result in out-of-turn diversions and would write off any possibility of maintaining rotational distribution, unless the cultivators concerned were unusually capable of policing their system.**

**The above discussion of tertiary systems underlines the fact that their design is not always straightforward. Generalized layout criteria can be formulated, but judgement at the field level has to be exercised in their implementation. Experience in South Asian irrigation is that construction of tertiary/field channel systems is the controlling factor in completion of new projects and often lags years behind "creation of irrigation potential" (the construction of the main canal system). The efforts of international lending institutions to expedite such works by making reimbursement against primary and secondary canal construction**

**conditional on completion of the associated tertiary systems have not entirely solved the problem. Training courses in tertiary distribution for irrigation engineers have undoubtedly assisted, but the subject remains a principal area of concern.**

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**Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)**

**Chapter 8 - Hydraulics of canal regulation and types of control structures**

## **Background**

**The subject of canal regulation, particularly as applied to third world situations, has generated a considerable volume of literature over the last decade, and considerable contention. Publications include recent monographs by the American Societies of Civil Engineers and of Agricultural Engineers, proceedings of the International Commission on Irrigation and Drainage, internal papers of international development agencies including the World Bank publications of academic and research institutions associated with agricultural development, and papers by professionals in developing countries (many of which are available through the Overseas Development Institute and the International Irrigation Management Institute).**

**Views on the subject expressed by competent professionals and agencies differ substantially. Differences stem principally from the perennial question of how the individual smallholder will react to situations of varying supply and demand. On the one hand is the view that only a simple preordained system of rotational supply will survive, as it certainly has in some situations. The view is tempered, however, by the experience that in other situations such a system is so obviously contrary to cultivator needs that the cultivators themselves reject it. On the other hand, there is the view that with modern technology water deliveries can be, and should be, much more closely matched to cultivator needs, a view which some experienced practitioners treat with considerable reservation, if not cynicism.**

**The subject of supply of irrigation from a partially regulated or unregulated source, in an area with capricious monsoonal climate, with highly independent small cultivators, is in fact a difficult one. Much as international lending**

**institutions prefer standard solutions to commonly encountered problems, irrigation in developing countries requires a situation-specific approach.**

**A feature of most South Asian irrigation schemes is that the supply of water in some seasons, particularly in some years, is less than what the cultivators demand. Distribution in such circumstances has to be on the basis of available supply, rather than on demand, i.e. it is to some extent a system of rationing.**

**The various supply/demand situations have been discussed in the last chapter, with comments on options available for canal management. Systems without storage (run-of" river) or with fixed high-flow season and low-flow season diversions call for no further comment. They are essentially supply-driven, with upstream control. On the other hand, systems with upstream storage (even where providing partial regulation only) offer the possibility of tailoring irrigation releases much more closely to supply and demand. The extent to which this possible flexibility is to be exercised determines the degree of sophistication of the hydraulic controls required and the intensity of management.**

**For purposes of illustration, a case is considered in which the storage reservoir will have net capacity of about one-third of the mean annual inflow. Rainfall in the irrigation area averages some 1300 mm annually, mainly recurring in the single monsoon season. Soils include both light well-drained uplands and heavy poorly drained low-lands, in close association. Most of the area is in holdings of less than one hectare, primarily owner cultivated. The area is underlain by hard-rock with limited groundwater potential (dug wells only). Basic irrigated crops expected to be grown in the area when the project comes into service are paddy and maize in the monsoon season, paddy being either monocropped or double-cropped, wheat**

**and oil-seeds in the dry season, and sugarcane as an annual crop. However, there is also keen interest in specialty crops including potatoes, tomatoes, and other vegetables, as well as bananas and citrus. Market projections indicate increasing desirability of diversification into these areas.**

**Design studies are to include a range of options for regulation of water distribution including possible provision of a high degree of flexibility extending either down to the individual farm, or alternatively to the 30 to 40 ha tertiary command.**

### **Downstream control with limited demand**

**From the cultivator's viewpoint, the most desirable situation would be to have water available "on demand", preferably demand by the individual. During periods in which supply of water to the system is not a constraint, such demands could be met, as far as the hydraulics of the operation are concerned, by a "level-top" arrangement of the tertiary. The tertiary in this case is virtually an elongated pool, or stepped series of pools if gradients so require, the levels in which are maintained constant, regardless of amount of withdrawal, by float operated gates at the head of each reach. Each cultivator has access to the tertiary, and within limits of the capacity of his outlet he can take water whenever he pleases and in whatever amount. This is "downstream control" both in the hydraulic sense, the gate at the head of each reach being controlled by the level downstream of the gate, and in the popular sense, supply being determined from the downstream end of the system (the irrigator) rather than being dictated by upstream agency.**

**However, when supply to the system is limited, there can be problems with this**

**utopian system. The total demands on the tertiary are reflected, reach by reach, up to head of the tertiary, at which point they become demands on the secondary or sub-secondary. If they are to be met, the gate on the outlet from the secondary must respond to the level in the first reach of the tertiary, maintaining it at its design elevation by discharging into the tertiary whatever flow is required to achieve that objective. The total demand of all the tertiaries served by a secondary becomes the demand at the head of the secondary, and this is passed on to the primary and eventually reaches the head of the primary, which is the outlet from the reservoir. Here a basic problem may arise. The reservoir may have insufficient water in storage to continue supplying at that rate or storage may be being held back for critically important irrigation at the beginning of the next season. Under these conditions, the controlling factor becomes supply rather than demand. Restrictions in water use must be passed on down the line, finally reaching the cultivator and unrestricted demand has to be substituted by limited demand or managed demand.**

**There are in fact two types of constraint on the downstream demand type of operation. One is in the hydraulics of the system, particularly in the control of the primary and secondary canals. While theoretically an infinite degree of hydraulic flexibility can be provided with capability of instant response to changes in demand regardless of length of canal the required control structures and their management can become very sophisticated. Work continues on more advanced computer-assisted dynamic operation of canal systems and float operated automatic controls. It can be assumed that most present problems will eventually be solved. More intractable is the second type of problem, the management of deficiencies in supply to cultivators while still preserving some degree of freedom in demand.**

**If the interests of the individual cultivator could be submerged into a collective common interest, a tertiary command of many small holdings with varying cropping patterns and varying water requirements could be served very well by a level-top demand-type of tertiary system. It would be communally managed with due regard to upstream supply constraints and benefitting from the flexibility in water distribution within the tertiary command which such a system provides. Decisions on the timing and amount of irrigation on each unit would presumably be on rational grounds.**

**However, for various reasons such a communal situation is not generally in prospect in South Asia, although it is approximated in some sugar-cane cooperatives, and the problem remains of how to regulate the use of a restricted supply of water by a group of cultivators acting as individuals. One possible solution is the Water Users Association discussed in a later chapter. Levying water charges in proportion to use, with rates possibly scaled upwards if consumption exceeds a certain rate or during periods of critical supply, could provide some degree of control. However, water meters have generally been short-lived in smallholder installations and collection of water charges remains a problem.**

**To summarize, the downstream demand type of system, while providing complete hydraulic flexibility in withdrawals from the tertiary, nevertheless, requires operational restraint during periods of limited supply. The same considerations apply to demand operation of the secondaries. When there is limited supply to the primary canal it would be unreasonable to respond to unrestricted demand in any secondary, although the hydraulic control at the head of each secondary is designed with that capability. While limited upstream supply may prevent full utilization of the hydraulic flexibility provided by downstream control, such**

**constraint can be minimized for short-term operation (e.g. 24-hourly or weekly) by provision of pondage at some point on the primary canal, if a suitable site can be found.**

**To reiterate, the key question determining whether a demand-responsive type of system would be workable is whether cultivators would exercise restraint in withdrawals during periods of restricted supply. If not, and in the absence of effective metering at the farm turnout, a demand system in the form of a level-top tertiary can become a "license to steal". The alternative system employing rotational supply within the tertiary command has a tertiary channel of much smaller capacity than the level-top. Even if the rotation breaks down and many cultivators divert from the tertiary simultaneously rather than singly, the total flow which can be diverted is strictly limited to the capacity of the tertiary intake.**

**However, a limited demand system does provide the ultimate degree of flexibility for irrigation of diversified cropping, in circumstances where the social structure and the character of the cultivator permit its use. The latter factors should be the starting point in consideration of possible application of a demand system in a smallholder situation.**

### **Upstream control with rotational delivery**

**The term "upstream control. is used in the popular sense, meaning that water releases to the primary canal are decided by the operating- agency, with consideration being given to the supply/demand situation, rather than being directly (hydraulically) responsive to downstream demand. The term will later also be used in the technical sense, implying operation of a gate (usually**



**automatically) in response to the water level immediately upstream of it.**

**The alternative approaches to the upstream control type of system have been noted in the previous chapter. They are as follows:**

### **System**

**(a) Continuous flow throughout, including tertiaries, with division of flow in proportion to area served, through use of flow dividers This system is widely used in small village schemes. In larger public systems the flow divider may be used at branches in primary and possibly secondary canals, but not at offtakes to tertiaries, as the resulting flow during periods of limited supply could be too small for efficient conveyance in unlined tertiaries and field channels, and for field application for non-paddy crops. Continuous flow throughout is not further considered herein.**

### **System**

**(b) Continuous regulated flow in primary canals, with full flow supply in fixed rotation to secondaries and their tertiaries. This system requires no operation of controls on the secondaries or the tertiary offtakes. However the proportionate reduction in supply/demand which can be accommodated depends on the divisibility of the secondaries into groups (discussed later). The system is particularly applicable to situations in which the supply in high and low flow seasons is assured (a special situation), and the ratio between the two can be accommodated numerically in designing the grouping of secondaries.**

## System

**(c) Continuous regulated flow in both primary and secondary canals, with full flow supply in fixed rotation to tertiaries. This removes the above constraint of divisibility of the number of secondaries and also permits tailoring of supply to the needs of individual tertiary commands. Any proportionate reduction in supply can be accommodated, including adjustment to conserve storage during rainfall. It is a very flexible system, but requires operation of hydraulic structures down the length of the secondaries.**

## System

**(d) Continuous regulated flow in primary canals, with full-flow supply in rotation to secondaries and their tertiaries, subject to a system of rotating priorities contingent upon the amount of water available. This system, widely used in N.W. India, can accommodate any degree of reduction in supply. Its principal disadvantage is the relatively long time between irrigations which may occur in low priority rotations. However, in the area in which the system is currently in use, canal irrigation is widely supplemented by farmer-owned tubewells. The system would not be appropriate in an area with limited availability of groundwater and planned diversified cropping, such as the case under consideration. It is not further considered herein.**

## System

**(e) Supply to portions of the service area is deleted for the entire season in dry years. This type of operation is appropriate only where a large proportion of the seasonal supply comes from storage and the deficiency is predictable. It is not further considered.**

**Of the systems listed above the two which could be appropriate to the project situation under discussion are (b) and (c). The difference between the two is that in alternative (b) supply to the secondaries is full-flow and rotational in periods of reduced supply or demand. While in alternative (c) it is variable (regulated) and continuous. As a corollary, in (b) rotational supply begins at the secondary; in (c) it begins at the tertiary. (In another usage, system (b) is "structured" down to the head of the secondary, system (c) down to the head of the tertiary). There are advantages and disadvantages with both alternatives and choice should be project specific.**

**Such group rotations, operated in conjunction with the project reservoir, may be sufficient to meet all seasonal variations in supply and demand. However, the period between irrigations may be a problem. The minimum practical duration of running time of a secondary operating on/off depends upon its length. If filling and emptying are not to take up too great a proportion of the "on" cycle the minimum practical running time for a secondary may be ten days. With a one on/two off rotation of secondaries (supply at one-third of maximum) the corresponding period between irrigations of a particular holding supplied once from its tertiary during each rotation would be thirty days. For a basic crop such as wheat this irrigation interval would not be a problem, provided that the dates of supply were known in advance. For specialty crops it would be excessive unless cultivators had farm storage, such as a large-diameter dug well. (It is presumed**

**that only limited groundwater is available in the case under discussion).**

**Apart from the practical length of the "on" period of the secondary, as previously noted there are soil conditions in which rotational operation of unlined secondaries would be unfeasible due to excessive sloughing of banks. There are also ground conditions (high watertable) in which rotational operation would be destructive to a lined secondary, due to back-pressure on the lining.**

**Summarizing, full-flow rotation of secondaries permits operation of the system at two or three levels of delivery, in addition to delivery at full capacity. As the rotational cycle is likely to be as much as three or four weeks this is not a rapid response type of operation, capable of short-term adjustment. It is more appropriate to making seasonal changes in rate of delivery which can be planned in advance, a situation which generally requires substantial reservoir capacity. The irrigation interval is relatively long during periods of reduced delivery, being determined by the length and filling time of the secondaries. The use of such a system is contingent upon ground conditions which permit on/off cycling of secondaries without deterioration of the canal section. The system is most appropriate where sufficient groundwater is available to provide supplemental irrigation of stress sensitive crops. Its principal advantage is simplicity of operation, gate operation being required only down to the head of the secondary.**

**In alternative (c), the secondaries and the primary canal operate continuously at variable flow. The tertiaries served by a particular secondary operate rotationally at full-flow, the tertiaries being grouped for this purpose in the same manner as the secondaries in alternative (b). However, there are many more tertiaries than secondaries, with more possible groupings, and the rotational period can be much**

**shorter due to the shorter filling time of tertiaries. Furthermore stability of the channel section under on/off conditions is not generally a problem with the much smaller tertiaries.**

**For example, with alternative (c), operation the situation is taken in which the supply to the area is reduced to one-quarter of system capacity, either due to reduced availability or low demand. The flow in the primary canal is reduced to one-quarter of capacity by operation of control structures, and also the flow in the secondaries. (The division of flow between primary and secondaries may be by flow dividers on the primary canal, discussed later). To reduce flow in the tertiaries to one-quarter of capacity would be ineffective due to high proportionate seepage losses in these small channels with such low flow and low field efficiency. Consequently, the tertiaries on each secondary are divided into four groups, one group at a time taking the whole flow in the parent secondary and operating at full design capacity. Each group operates for three days on and nine days off, for a rotational cycle of twelve days.**

**While such an arrangement may appear straight-forward, and it is indeed operable, it poses a number of hydraulic and other operational problems. First, to permit full-flow diversion to tertiaries the water-level in the parent secondary must be maintained at or near full supply level, even while flow in secondary is reduced to one-quarter of capacity. This requires a considerable number of hydraulic structures on the secondary and their operation. Second, and probably more importantly, the tertiary intakes have to be gated and the gates must remain closed other than during the appropriate rotational turn. The question is what agency operates the tertiary intake gates, and ensures that they are not opened out of turn, particularly in periods of severely reduced supply when crop survival**

**is at stake.**

## **Hydraulic controls on secondary and tertiary canals**

### **Downstream control**

**As noted earlier, limited-demand downstream-control type of operation could be provided through a level-top canal or stepped series of such canals, constituting the tertiary, to which all farms would have access. Controls on the tertiary would consist of a series of weirs, each with gates automatically activated by the level in the reach immediately downstream of the weir, serving to maintain the downstream reach full at all times. Gates to each farm turn-out would need to be adjustable by the cultivator, providing flexibility as to the rate of flow diverted to the farm at any time. A flow recording device either at the head of the tertiary or at each turn-out would also be required.**

**In view of the problems of maintaining level-top float controls in open tertiary canals a more feasible arrangement could be to substitute a buried pipe for the tertiary canal if ground-slopes provided sufficient gradient for economic use of pipe. A valved outlet would serve each farm. If the ground-slope were excessive for the use of low-head pipe in a demand type of operation, the head could be reduced where required by the use of float-operated stand-pipes or other pressure-reducing devices. It is noted that a closed pipe system with valved outlets, providing supply on demand, subjects the pipe to significant hydrostatic pressure. The alternate use of pipe as part of an upstream control system, sometimes referred to as a "buried channel" system, does not.**

**Structures on the secondary canal supplying a demand-type of tertiary operation would automatically maintain the required level in the secondary at each outlet, also the setting of the tertiary intake gate required to maintain the level in the first reach of the level-top tertiary. Structures on the primary canal would serve the same type of function for supply to each secondary, but the operation would be more complex in the case of the primary canal due to its greater length and dynamic effects (surges) in its operation.**

**It will be evident from the above discussion that the structures required for the operation of a system providing limited-demand type of service down to the individual smallholder, while technically feasible, would not be particularly simple in nature. In the small irrigator environment, where usually only the most robust structures survive, such a system could be entertained only under the most favorable conditions of cultivator support.**

### **Upstream control**

**As previously discussed, there are two alternative types of operation based on upstream control. In the first (alternative (b) above) both secondaries and their associated tertiaries and are run rotationally on full flow. Although there are limitations in the applicability of this system, noted earlier, it is undoubtedly the simplest with respect to provision and operation of hydraulic structures. At the tertiary level, particularly if the system is designed to supply one farm sum-out at a time, the structures required are simply turn-outs, checks, branch structures, and drops. All of them are gated, the gates being either fully open or fully closed. The only problems are leakage of the closed gates, and theft of gates. Whether they are made of wood, sheet steel, or concrete tile, gates found useful for**

**household purposes are widely subject to theft. In place of the missing gate, closure is usually made by brushwood and mud, excavated from the channel bottom and wedged across the gate opening. In one design, the conventional gate is backed up by a grillage of embedded steel rods extending across the opening, behind the gate slot. The rods facilitate such extemporaneous closure.**

**The structures down the length of the tertiary (farm turnouts), in turn, divert the full flow in the channel. On the other hand, the structure at the head of the tertiary (the tertiary intake) diverts only part of the flow in the parent secondary. As the secondary always runs at full capacity with this system, control of flow to each tertiary intake is relatively straight forward. It could be achieved by use of a flow divider at each intake, as the aim is to divert a proportion of the flow in the secondary to each tertiary. However, flow dividers are not regularly employed at tertiary intakes in view of their cost (the divider is essentially a weir, and extends across the full width of the secondary), the number required, and the fact that a hydraulic drop in the secondary is required at each divider and sufficient head may not be available for a series of such drops. The type of structure normally used for the tertiary intake is hydraulically a submerged orifice, in some cases simply a pipe or culvert extending through the canal bank. More sophisticated structures have shaped entry and may incorporate energy recovery at the exit from the culvert. The virtue of the orifice type of intake is that its discharge is affected by head (i.e. by level in the secondary) to only a relatively small degree only. In fact, it is proportional to the square root of head, and over a range of level in the secondary the proportionate change of flow to the tertiary intake, due to a change in level in the secondary, can be approximately the same as the proportion change in flow in the secondary itself. This feature, sometimes referred to as "modularity" is desirable, as the flow or the level in the secondary may not always be exactly as**



**planned. It is preferable that the tertiary intakes divert a proportionate share in the deficiency or excess of the flow in the parent canal. The A.P.M (Adjustable Proportionate Module) of the N. W. Indian irrigation systems is of this type, diverting not only a "modular" share of the flow in the secondary but also a corresponding share in the silt being carried by it. An ingenious type of intake structure of French design has capacity near-constant over a range of head. Such a structure is appropriate to a system in which the flow in the secondary is closely regulated, and the flow to be diverted at each tertiary is consequently also closely defined. In a less well regulated system, however, where the flow in the secondary is likely to vary, proportionality of diversion at the intake rather than a fixed amount of diversion is the desirable feature.**

**With the type of operation in question, the secondary runs at full capacity only (other than during filling and emptying), which greatly simplifies requirements for control structures on the secondary. The water-level profile, and the level opposite each tertiary intake, is determined by canal geometry and within limits is predictable. It is required to be known, for purposes of tertiary intake design, at one flow only, i.e. full flow. Particularly if the capacity of the intakes is adjustable (one-time adjustable) and can be matched to actual water levels in the secondary determined during initial operation, formal hydraulic structures for control of level in the secondary at tertiary intakes need not normally be required. If for any reason such structures are, in fact, needed for stabilization of water-levels (such as at drops), their setting can remain fixed, and related to full flow only.**

**In the second alternative ((c) above) the flow in the secondaries is not rotational. It is continuous, the rate varying in accordance with supply or demand. The tertiaries operate at full capacity, but in groups, rotationally. For instance, if the**

**secondary is running at one-third design capacity, one-third of the tertiaries operate at a time. The tertiaries may be grouped as the upper one-third, followed by the middle third, and finally the downstream third, the cycle then being repeated. Alternatively every third tertiary down the whole length of the secondary, beginning with the first, may operate as a rotational group, followed by a similar group beginning with the second tertiary, and finally the last group beginning with the third tertiary. The cycle is then repeated. The structures required within the tertiary command (the farm turn-outs, etc), and their operation, are the same as in the alternative (b) system discussed above. However, the situation in the secondary, including the outlets to the tertiaries, is substantially different. Because the flow in the secondary may vary from full capacity to as little as one-quarter of full-flow, hydraulic controls are required down the length of the secondary to maintain water levels at or near full supply level adjacent to tertiary outlets, thus ensuring that the outlets operate at design capacity.**

**Several types of structure could be used for this purpose, with either fixed or variable geometry. Conceptually, the simplest is a fixed weir with a crest sufficiently long that the range in depth over the crest between low-flow and full-flow (i.e the range in level in the secondary at that point) would have an acceptably small effect on the discharge in the adjacent tertiary outlet. As an example, a secondary of  $1.0 \text{ m}^3/\text{sec}$  ( $35 \text{ ft}^3/\text{sec}$ ) full flow capacity would require a weir of crest length of about 8.5 m (28 ft) if the range of level between full flow and one-quarter flow over the weir were to be kept at no more than 10 cm. The latter range would cause a change in discharge capacity of the adjacent tertiary intake (design head 30 cm) of about 20%, which would probably be acceptable. The point of significance is that the required weir crest length is 8.5 m whereas**

**the width of a canal of this capacity is about 2.5 m. The weir would consequently need to be U-shaped in plan, extending about 4.25 m downstream to provide the desired crest length. This is the classical "duck-billed" weir. It is not a particularly low-cost structure, and the practicability of using it in a specific case would depend upon the number of such structures required, i.e. the spacing along the canal, which is determined by the gradient of the canal alignment.**

**The alternative to a fixed weir is a weir with moveable gates, adjusted to maintain levels in the secondary whenever the flow is changed. For small canals the gates could take the form of manually placed vertical "needle-beams" (which control the width flow over the weir crest), or radial or leaf gates. More sophisticated automatic float-controlled gate are also available.**

**Although the type (c) system with continuous regulated flow in the secondaries provides highly desirable flexibility in supply, the fact that hydraulic structures on the secondary have to be adjusted in the course of such operation is a disadvantage. Tertiary intake gates necessarily have to be opened and closed rotationally. Gates on the level control weirs in the secondary also have to be operated, unless duck-billed weirs or automatic float-controlled gates are used. However, with appropriate design it is possible to confine such gate operation to accommodating changes in rate of delivery in the secondary, and to avoid the need for adjustment at each rotation of the tertiary groups.**

**Maintaining the latter rotations and avoiding unauthorized opening of tertiary intakes out-of-turn is, in fact, the principal concern with this type of operation. It is necessary to have sufficient staff by the operating agency to maintain supervision of secondary canal structures including tertiary intakes or farmer**

**organizations capable of operating the secondary canals as well as the tertiaries.**

## **Hydraulic controls on primary canals**

**As the small cultivator is not generally involved in operations at the primary canal level, technical details of primary canal control structures are not relevant to this discussion. However, the extent to which irrigation systems are designed to be demand-responsive at the tertiary level has a major influence on the operational requirements of primary canal controls.**

**With currently available technology it would be technically possible to make primary canals instantly responsive to changes in demand. It would, however, be very costly to do so and unjustified when problems in management of limited-demand at the small cultivator level, discussed earlier, rule out such operation at least for the immediate future.**

**Of more immediate concern is the need to design into the primary system controls which can accommodate possible future developments, such as a change in the direction of greater crop specialization in various areas of the project command, with consequent changes in allocation of water to particular secondaries and in capacity required at structures. The possibility of a future change from on/off full flow rotation of secondaries in favor of continuous regulated flow, which could affect design requirements of outlet structures on the primary canal, should also be taken into account (Plusquellec 1985 and 1988, Le Moigne 1988).**

## **Production of small hydraulic structures**

**Supply to smallholders requires a large number of hydraulic structures at the**

**tertiary level. For instance, a 20,000 ha service area with holdings averaging one hectare in size would need 500 to 600 tertiary intakes and some 20,000 farm turnouts, together with a large number of "junction structures", checks, and drops.**

**As previously noted, installation of tertiary structures has been responsible for much of the delay (often several years) between completing the main canal system and bringing the whole command into effective operation. Traditional brick construction of small hydraulic structures is satisfactory technically, but installation is very slow and limited to the dry season. The alternative material is pre-cast concrete. Manufacture of the units can continue throughout the year, and installation, although also limited to the dry season, is relatively rapid and requires largely unskilled labor.**

**While pre-cast concrete is undoubtedly the indicated solution to the problem, experience with small pre-cast structures underlines several design considerations unique to the smallholder situation. The tertiary outlet, in particular, is generally regarded by cultivators as the main constraint on the rate of diversion to their holdings, which is certainly true. The structure is consequently subject to attack and much ingenuity is devoted to increasing its discharge. Small structures in general are also particularly susceptible to destructive soil pressures and movement in expansive clays, a factor which operates against the use of light-weight sectionalized construction in pre-cast units. Robust, relatively heavy construction is preferable, economy being served by low labor requirements in installation rather than in cost of materials.**

**The problem of theft of gates on tertiary outlets and farm outlets, also on junction**

**structures, has been discussed earlier. No material has proved immune and chains and padlocks are equally susceptible. The only material not subject to theft is soil, and this is eventually the fall-back material for closures. Repeated taking of mud from the channel-bed adjacent to structures, for closure purposes, can result in depressions which remain water-filled after each rotation, eventually seeping away and representing water-loss. The problem cannot be entirely avoided, but it can be reduced by designing the structures so as to minimize the amount of soil, or mud, required for closure. Steel bars embedded for this purpose in the throat of the opening have been incorporated in some designs.**

**Means of providing a tamper-proof adjustable gate for tertiary outlets has received much attention in the past, but without notable success. None of the operational systems discussed above in fact require adjustment of the intake in normal service; they are all full-flow rotational systems. Capability of one-time adjustment of capacity at the time of initial installation is, however, a desirable feature, for two reasons. First, because the size of tertiary command unavoidably varies, the appropriate capacity of outlet also varies from one to another. It is convenient to deliver standardized pre-cast units to the field and to make the appropriate final adjustment to capacity at each location. Second, the head in the intake and its capacity are functions of water-level in the parent secondary and in some cases water-level in the tertiary (if the intake is operating "submerged"). Both levels can be estimated in advance approximately only. It is convenient to make final adjustment of the intake in the field, in accordance with actual measured levels. One method of doing so is to supply the intake in the form of a standard body with oversized opening in which an insert sleeve is permanently grouted at the site. The sleeves are supplied in a range of sizes of opening, from which selection is made appropriate to the size of service area and the actual head**

## on the particular intake.



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**Introduction**

**Methods of matching varying supply and demand have been discussed above.**

**Actual operation involves forecasting of inflows and water demands, planning operational schedules, monitoring the supply/demand situation as the season progresses, and modifying delivery schedules where necessary. In addition to these planning functions, the project facilities must be operated from day to day, and regular and periodic maintenance must be carried out. As will be apparent from earlier discussion, operation can be largely supply-oriented and relatively simple, or demand oriented and more complex. The first type of system requires fewer operational staff and has least exposure to interference with structures. The second requires more staff and is more susceptible to interference with, or damage to, structures. On the other hand it can tailor supply more closely to demand.**

**In the following, selected technical or administrative subjects relevant to O and M are discussed, with particular attention to problem areas.**

### **Inadequate budget for O and M**

**Poor performance of an irrigation system is often due to needed repairs long left untended and a general deterioration in effectiveness of supply. Cultivators take the law into their own hands under these circumstances and a state of operational anarchy develops, with further deterioration of the infrastructure. Poor design in the first place may be a contributing factor, with the system incapable of delivering as planned, but the primary source of the problem is usually budgetary. Funds provided are barely sufficient to meet staff salaries, with little remaining to meet essential repairs. Water charges are insufficient to cover O and M costs, and in any case they are paid into Treasury, not to the irrigation agency. Funding for O and M comes from annual appropriations from general revenues. It is usually paid**



**reluctantly and is subject to official "norms" regarding annual cost per hectare, regardless of actual needs.**

**Government reluctance to spend money on repairs where the damage has been inflicted by the cultivators (e.g. regulating structures with gates repeatedly broken) is understandable, particularly in view of cultivator unwillingness to pay due water charges. On the other hand, cultivators are reluctant to pay for water supply which is unreliable due to lack of maintenance.**

**Funding for new construction is, in fact, easier to obtain than funding for O and M, and this also applies to financing by international agencies, which do not usually cover recurrent costs. Specific agreement regarding budgetary provisions for O and M, from one source or another, should be prerequisite to new irrigation construction or improvement projects.**

### **Desilting of canals**

**A major item of cost in canal maintenance can be removal of silt. In the design of early canals in the Indus basin much attention was given to achieving a balance between deposition of silt and erosion from the canal-bed ("regime" flow). However, factors other than silt balance often determine the design of canal systems, and in projects diverting directly from major rivers without intervening storage siltation of canals remains a problem. Rivers originating in the Himalaya are particularly heavily silt-laden in the high-flow season. Provision of de-silting basins at primary canal head-works can be a solution in major projects, although still posing a problem of disposal of silt deposited in the basin. More frequently, periodic de-silting of the canal system will be necessary.**

**Intentionally or not, a proportion of the finer fraction of the silt entering a canal system (unless removed by headworks de-silting) will eventually find its way on to the fields. The silt is generally beneficial, but in some cases it is not. Examples are highly micaceous silts, which can have a very adverse effect on surface soil structure, and certain organic sediments which can be toxic when excavated from canal bed and disposed of on adjacent fields. Except where the potential silt problem is very obvious, practice has generally been to observe the extent of siltation which develops, before taking remedial action. The one provision which should be made in initial designs, however, is access for prospective canal-side silt clearing equipment. This requirement may be in conflict with policies regarding "public forestry" canal-side tree plantations, or may require restriction of such planting to one bank only.**

## **Weed control in canals**

**Depending upon local circumstances weed control can range from a relatively minor problem to a major one, almost prohibitive in some cases. The offending vegetation may be rooted in the canal bed, floating, or it may be canal-side phreatophytes. The problem can be aggravated by the presence of lateral storage (otherwise highly desirable), which provide still-water conditions and an ideal nursery for aquatic plants which then spread into the canal system.**

**A degree of control can be affected by un-watering of canals for a month or more in the hot dry season, a very desirable practice from the maintenance viewpoint, but not always practical if perennial crops are being cultivated, unless alternative source of water, such as groundwater, is available. Furthermore, in conditions where watertable is relatively high throughout the year, annual un-watering of**

**canals will not materially assist in control of canal-side phreatophytes. The latter are particularly troublesome with smaller canals (secondaries) as the proportionate reduction in water-way due to encroachment from canal-side vegetation is greater than with large canals. A 50% reduction in carrying capacity is common. The phreatophytes are frequently deep-rooted hardy plants which rapidly recover after cutting unless all roots are removed, a very difficult operation in most circumstances. Control by herbicide spray could probably be effective, but is not usually practiced in the South Asian area due to high cost and the need for frequent retreatment. Manual cutting is the only course, presenting a departmental budgetary problem unless the work is undertaken by cultivator organizations at their cost.**

**Bottom-growing weeds can be controlled biologically under certain conditions by fish, notably the species of Tilapia. However, in addition to their sensitivity to temperature and other conditions, and the need for re-seeding from nursery, Tilapia are edible. In a developing countries situation, this ensures their capture for home consumption. Weed control by Tilapia has not yet proved practical in the region under discussion, except under closely-controlled conditions.**

**Control of water-hyacinth, the most widespread of the floating plants, continues to be the subject of intensive research. To date, however, it remains a problem, with mechanical or manual removal the usual expedient. This can be a major task in heavily infested areas where flow-regulating structures can be blocked and virtually submerged by floating masses of the plant. Water hyacinth remains an ecological problem of the first magnitude.**

### **Operation of partially completed systems**

**The earlier discussion of alternative methods of operation of canal systems was in the context of completed projects. However, every major project, for which construction and development may extend over ten years or more, goes through a stage of supplying upstream portions of the service area while construction of the remainder of the canal system continues downstream. During this interim period the amount of water available in relation to the size of the area as yet under irrigation can be much more than when the full project area comes into service. The issue is whether cultivators in the upstream area should be given the interim use of this temporarily surplus water.**

**The case for such practice is that additional food production may thereby be achieved, a compelling argument in periods of scarcity. The case against such practice is that upstream cultivators may adopt high water-use crops such as paddy during the interim period, or poorly efficient irrigation methods, and may be very reluctant to give up the use of the surplus water in favor of downstream cultivators when the latter finally come under irrigation. Past experience indicates that this reluctance may translate, at worst, into acute political pressures by the cultivators, also technical anarchy and loss of control of the distribution system. No satisfactory solution to this problem, a commonly occurring one in greater or lesser degree, is yet apparent.**

### **Night irrigation**

**This is a perennial issue. Irrigation at night has many disadvantages. Field distribution of water is less efficient than in the daytime due to lack of visibility, although evaporative losses may be lower. Such irrigation is also most unpopular with cultivators for a variety of reasons, and it may be dangerous (dacoits, wild**

**animals, snakes trodden on in the darkness etc). Reluctance to remain in the fields at night contributes to the poor field application efficiency, as irrigation streams are often left untended, running to waste or flooding.**

**With the disadvantages of night irrigation so evident the obvious question is how can it be avoided and at what cost. It is largely a question of storage, hydraulic control on the canal system, and canal capacity. In a reservoir-controlled scheme the reservoir itself could theoretically provide the overnight storage of inflows, and with sufficient control structures the canal system could (again theoretically) be made instantly responsive, permitting shutting down the entire system at sunset and re-commencing deliveries at dawn. However the cost of such a system would be prohibitive in most situations, and other solutions are sought, notably providing storage within the canal system, further downstream. This would also be necessary with a run-of-river scheme, which has no upstream storage, in which case diversion into the primary canal must continue through the night or water will be lost to the project.**

**The most convenient location of over-night storage, from some points of view, would be in terminal pondages supplying each tertiary or in the tertiaries themselves. As previously discussed, however, sites suitable for terminal or lateral pondages with capability of gravity inflow and outflow are rare. Pumping either into or out of the pond would generally be required, and the pondage created by embankment construction, occupying a significant area. Both requirements would be substantial obstacles to this solution.**

**Storage within the tertiaries, by increasing their sectional area to provide elongated overnight pondage, has been tried but only once. This was in the Gezira**

**scheme in the Sudan. Topographic conditions (near-flat gradients) in that area were favorable to such a system, but it has nevertheless not been repeated. In more typical rolling topography it would not be practical.**

**Night storage within the secondary canals, associated with cyclic operation of the primaries (except in run-of-river situations) or night storage within the primary canals themselves, remain technical possibilities which could warrant investigation in particular situations. However, cost would be high. The traditional reluctance of irrigation engineers to seriously consider such systems is not simply due to their unawareness of the problems of night irrigation, but to acute awareness of the technical problems and cost of avoiding it.**

**In areas of water deficiency, night irrigation is in fact regularly practiced by cultivators, probably at reduced efficiency. It is in situations where the need for canal irrigation is not so pressing that cultivators may simply forgo their night-time share or headend cultivators may illegally extend their hours of day-time irrigation at the expense of tailend cultivators who then are forced into use of the night-time supply rejected by the headenders. This is in some respects a solution to the problem, except the question of night-time irrigation efficiency.**

### **Monitoring of project performance**

**Monitoring of an irrigation project covers several different functions at successive stages of its development. In the construction phase, progress is monitored for contract management purposes and as an input to "project supervision" and control of disbursement of loan funds by the lending institution. On conclusion of the work, a completion report is filed, and later, when the project is nominally in**

**full operation, the lending institution may prepare an ex-post evaluation report dealing primarily with economic performance and the social impact of the project (Malhotra 1987).**

**The area of monitoring discussed here is the technical performance of the project, including water delivered, area irrigated, irrigation efficiency, etc. Of particular importance is the feed-back of such information and its utilization in management of system operation and maintenance. For a number of reasons, the latter function is notably absent in most South Asian irrigation projects. First, such data collection is generally assumed to be for purposes of criticism and is given only token support by operational staff. Second, information on timeliness and reliability of water deliveries at the farm level is subjective at best and requires considerable judgement on the part of the collector. Thirdly, analyses of the information gathered, usually by a mid-level officer is unlikely to be particularly candid for fear of giving offence to higher level in the same Department. Information is usually simply filed, and the results of analyses, if ever carried out, are of retrospective interest only. They are not available as an input to current operations. In any case operational decisions are taken only at senior departmental levels not by monitoring staff. If senior operational staff are not sympathetic to the process of monitoring and evaluation, it becomes ineffective unless pressure is exerted by the financing agency, but that agency is no longer associated with the project after completion of construction. Notable successes in monitoring and evaluation do occur, but only where top-level management is convinced of its value and takes personal interest in its execution.**

**Application of computers to irrigation system operation**

**Computer application to the operation of major Western irrigation systems may be highly complex, involving main-frame computers for near-instantaneous analyses of dynamic flow situations in large canals or for their actual control. Such major systems are also found in developing countries and could be candidates for such computer installations. However, they are the exception and are outside the scope of present discussion. More pertinent is the question of how the computer may assist in the operation of more common less complex schemes.**

**Such assistance can cover several areas. The most obvious is in recording and processing of data, which even the simplest desk-top computer does very well. The information may be physical data on all components of the canal system, the service area of each canal and outlet, actual water deliveries, rainfall, etc. It may also include inventories of equipment and spare parts, as well as service and maintenance records of all irrigation facilities and equipment. Finally, it may include complete property ownership records and billing and accounting data. In this function of data recording the computer is simply replacing the written record, but with the facility for instant recall and also for processing the data. It can also reproduce in quantity the forms required for reporting the data, in the manner required for entry into the computer.**

**In addition, the computer may be used as a calculator, including for instance, the estimation of consumptive water use for a range of crops and crop-mixes and climatic conditions. This information may or may not be used directly in scheduling of water releases, which may be influenced by supply considerations, but it is obviously required for planning of such operations. Calculations may also include generation of hydraulic profiles in canals under various steady state conditions. With appropriate software all of the above functions can be operated**



**by regular staff with little special training and in view of the great convenience which they provide they are likely to continue to be used if the computer facilities are provided.**

**In a more sophisticated category is the analysis of varying-flow situation in main canals, possibly extending to computer modeling of the complete hydraulic system. Such applications is likely to be the exception. It would require special programming and considerable computer skills on the part of the operator.**

**Finally, the computer, with appropriate software, may be used for economic optimization exercises, covering a range of agricultural and irrigation options and inputs as well as market conditions. Commonly referred to as "computer games", such exercises are not expected to be routinely used as an input to day-to-day system operation, but they undoubtedly are of value in promoting understanding of the economics of irrigation at project and farm levels.**

### **Social and political pressures in system operation**

**In addition to technical factors, social and political pressures may also have profound influence on the functioning of an irrigation project. The question of individual and group interests in relation to operations within the tertiary command has already been referred to, and will be discussed later in connection with cultivator organizations.**

**There are two other factors, much less discussed, which can have a major influence on system operation. The first is political pressure, exerted by local elected representatives on field staff of the irrigation department, to secure**

**operations favorable to their constituents. Such pressures can be acute during periods of deficiency when it is necessary to ration, restrict supply to certain types of crop, or delete supply to portions of the command. The pressure is reinforced by the ability, at political level, to secure desirable posts or transfers for Departmental staff and equally the threat of undesirable transfers.**

**The second factor is the existence in some areas of a parallel unofficial system of water levies. Together with kick-backs from contractors at established rates, the funds are reported to flow upwards for disbursement at various levels in accordance with traditional percentages. This system is not everywhere practiced, but where it is its functioning is well organized.**

**The ethics of such practices are not part of this discussion, but rather their implications regarding system operations. Imposing an unofficial levy for the supply of water implies the ability to withhold supply if the levy is not forthcoming. This requires the existence of control structures. In fact, the more sophisticated the control system the more susceptible it is to such mismanagement. This observation is not intended as an argument for universal basic simplicity in system design, but it does underline the need for consideration of the factors discussed, where they apply, in deciding upon a particular operational system.**



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**Design and Operation of Smallholder Irrigation in South**



## Asia (WB, 1995, 134 p.)

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  - Reasons for lining**
  - Causes of deterioration canal linings**
  - Construction materials for primary and secondary canal linings**
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## Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)

### Chapter 10 - Durability of canal linings

#### Reasons for lining

**The question of whether to line a canal system, and which categories of canal to line, involves technical, economic, and financial considerations. Canal lining is a major cost item, but the record of performance ranges from excellent to very poor, underlining the need for full analysis of alternative courses and technical options in each particular case.**

**A principal reason for lining may be to reduce seepage losses. However, as an alternative to lining, seepage may be recoverable by groundwater extraction. Indeed recharge by canal seepage may be highly desirable if the quality of the groundwater and the nature of the aquifer favor well development in the particular area. However, if the groundwater is unsuited to irrigation or if the underlying**

**formation is not favorable to well development, canal seepage may present a drainage problem. To illustrate, a canal was excavated in thinly-bedded sandstones dipping parallel with the ground surface, down slope from the canal. The bedding planes provided seepage paths for water, but insufficient yield for economic well development. The seepage produced waterlogging for a distance of about a kilometer down-slope from the canal and paralleling it for several kilometers. Lining was the only available solution, justified in this case by the loss of production from the water-logged area. Some credit could also be taken for the value of water lost from the canal, although seepage water is seldom entirely lost. It may reappear downstream as a contribution to stream-flow and may subsequently be developed for irrigation (although at some cost). However, it is lost to economic use if it joins a body of groundwater of quality unsuited to irrigation or if it is by unproductive evapotranspiration in areas of waterlogging caused by the seepage. A regional rise in watertable and threat of extensive waterlogging may in fact be the principal reason for lining a canal system. Even where the character of the formation is suited to groundwater development, cultivators in the areas may not generally be in a financial position to install wells, at least not on a sufficient scale to control the rise in watertable, preferring to use canal supply only. Further, once waterlogging has occurred the economic productivity of the area falls and cultivators are even less likely to be willing to undertake well installation. Large scale canal lining may than be the solution.**

**Another factor which may influence a decision to line is erosion, particularly in the vicinity of structures or bends in canal alignment. In some clay-soils (previously discussed) the impossibility of preserving the section of an unlined channel due to sloughing or lateral erosion of the canal banks may be a reason for lining.**

**The tertiary canal requires special consideration in the matter of lining. In view of the small flow in relation to the "wetted perimeter" of these small channels seepage in permeable soils can cause disproportionate loss. Lining of at least the main stem of the tertiary may be necessary in such soils, if reliable delivery is to be maintained at the outer perimeter of the tertiary command. In dune sand areas, lining of the whole length of the tertiary is virtually mandatory. Another reason for considering lining of tertiaries is heavy infestation with phreatophyte plants (particularly bull-rushes or "typha") in areas of perennially high watertable. Maintenance of a small unlined water-channel in such circumstances can be very difficult. This raises the question of responsibility for maintenance of tertiary channels, lined or unlined, also for meeting the cost of their construction. Payment by cultivators for the cost of tertiary lining has been successfully practiced to a limited extent, but is very much the exception. Government view, and that of some international financing agencies, is generally that tertiaries are the communal property of the cultivators within the tertiary command, not part of the canal system proper. The cost of construction and subsequent maintenance should therefore lie with the cultivators. Cultivators understandably take the opposite view. Their position is complicated by the fact that lining of the main stem of the tertiary, primarily for the benefit of cultivators on the outer (downstream) perimeter, does not significantly benefit upstream cultivators. So why should the upstream cultivators contribute to its cost? Acceptance of the idea of communal property does not apparently extend to acceptance of communality of costs. Efforts to provide credit to cultivators to meet the cost of lining, or to set up intermediary institutions which borrow for that purpose and endeavor to collect from cultivators, have not made payment of the cost of lining of tertiaries any more palatable to cultivators and have generally been unsuccessful. It has usually**

**become a Government cost, and it can be a very substantial budgetary item. For this reason lining is often limited to the main stem, or a certain proportion of the length of the channel.**

## **Causes of deterioration canal linings**

**Deficiencies encountered with linings are generally either leakage or physical deterioration, and frequently the two are associated. As linings are exposed to a wide range of temperature and to cyclic wetting and drying, some degree of expansion and contraction of any form of rigid lining is inevitable, whether the material is concrete, brick, or masonry. The movement is either at joints, as in formed-in-place concrete linings and pre-cast lining units, or if joints are not provided, it is distributed in capillary cracks as in brickwork or masonry. Leakage occurs at cracks, to a degree depending on their width and at joints unless flexible seals are provided.**

**A relatively small incidence of cracking or joint leakage can cause a seepage rate not significantly different from that in unlined section or not sufficiently different to warrant the cost of lining, if reduction of seepage losses is its purpose. The seepage can also be the cause of progressive deterioration of the lining, which in turn increases the rate of seepage. The deterioration may result from slow erosion of fine material from behind the lining at the leaks due to movement of water in and out with fluctuating level in the canal. Collapse may eventually result. More commonly seepage attracts the root systems of canal-side plants, behind the lining, and pressure from the expanding roots displaces portions of the lining, again increasing seepage. Plant growth inside the canal at cracks or joints, particularly just below water-level, is also frequently disruptive.**

**Deterioration at initially small seepage sites can be aggravated by particular circumstances, notably the presence of gypsiferous soils behind the lining or the activity of crabs. Gypsum is highly soluble, and a slow leak can, in time, form a large cavity behind a lining, resulting in its eventual collapse at that point. The design of linings in gypsiferous soils is a special subject and calls for virtually zero seepage. Lining is resorted to in some areas because of severe leakage in unlined canals caused by the tunnelling activity of crabs. However, the same activity can cause the collapse of linings in some situations. This typically occurs where a canal, in embankment, runs at two different levels, seasonally. While the canal is at low level crabs may form tunnels, at a location of significant seepage, extending from water-level down to a seepage pool at the toe of the canal embankment. When the canal level is later raised seepage into these tunnels rapidly increases, causing erosion and cavity formation behind the lining, with eventual collapse. In such circumstances a very low level of initial seepage and crab control measures (drainage of the seepage pool) may be necessary.**

**Seepage is often initiated by structural cracking of a lining due either to differential settlement of the fill supporting the lining or to soil movement due to changes in moisture content if the canal is excavated in expansive clay soils. The latter can be a major problem in extensive areas of such soils, aggravated by the fact that an unlined section may not be a viable option in these soils due to the incidence of sloughing. The solution to the problem is generally excavation and replacement of the expansive clay in the vicinity of the channel with non-expansive material, an activity of substantial cost if haulage of the latter material is involved. A second alternative, applicable to smaller secondary canals and to tertiary channels, is to construct the canal in the form of a flume of reinforced concrete, with the base of the Qume being at ground surface. The freestanding**

**sides of the flume are then not exposed to expansive soil pressures.**

**Structural failure of a lining may also be caused by hydrostatic back-pressure on the lining when a canal is drawn down or emptied. This may occur when a canal is in cut, and the watertable in the vicinity of the canal is high. On reducing the counter-balancing internal hydrostatic pressure on the lining, as a result of lowering the level in the canal, the lining is forced inward either collapsing or cracking sufficiently to relieve the external pressure. The solution to this problem is to provide drainage behind the lining, exiting into the canal via a one-way valve. However, the design of such drainage and particularly of the valve is the subject of continuing debate. As discussed earlier in connection with alternative operational systems, the problem of backpressure on linings in some circumstances can be an argument against rotational operation of secondary canals.**

**Efforts to reduce the first cost of canal linings may set the scene for early deterioration, and this is commonly the case with some types of masonry lining. A substantial masonry lining can have almost indefinite life. However, when the desire to reduce first cost, or inadequate quality control result in a lining consisting of random stone only nominally set in mortar, finished on the inside surface with a thin mortar plaster, deterioration can be very rapid. Crazeing of the plaster on exposure to the sun and the frequent wetting and drying leads to peeling, which in turn exposes the very pervious, poorly cemented masonry to full hydrostatic head from the canal. Rapid seepage results, with leaching of the mortar, and failure.**

**Quality control is in fact a perennial issue in construction of canal linings. Cement is an expensive material, which provides a strong incentive for the contractor to**



**"economize" in its use, with mutual distribution of the resulting "savings" Providing water for curing concrete, plaster, or mortar in brickwork, or for moisture control in embankment compaction, can also be a costly item for the contractor, who may have an incentive to reduce or eliminate its use, often with the collaboration of the inspector who may be under considerable pressure to cooperate. More extensive use of the non-destructive methods now available for testing the quality of completed work, provide independent back-up to routine inspection during construction and could help minimize this problem.**

**Finally, an important element in the deterioration of linings is often the cultivator himself. Stone slabs used in lining of some secondary or tertiary canals and pre-cast concrete slabs or tiles used for the same purpose are obviously of considerable value for paving or other home improvements, particularly in a muddy wet-tropic environment. Theft of such items from canal linings is consequently widespread and can have a bearing on the selection of these types of lining, versus other options, as well as on the method of their placement in the lining (to render removal more difficult).**

### **Construction materials for primary and secondary canal linings**

**In view of the adverse effects of cracking on seepage and deterioration of rigid linings the use of flexible plastic sheet has received much attention in recent years. It may be used by itself, as the single lining material, or in association with other materials. However, while plastic sheet is now widely used in Western countries as a lining for storage ponds, its use as a single canal lining under South Asian conditions faces certain problems unique to that area, notably access of water buffaloes. The hooves of buffaloes easily penetrate a plastic lining, unless**

**the lining is buried under soil cover. However, the soil in that situation is fully saturated and very soft, offering little protection from hoof penetration unless of substantial depth. Such a lining system would, in fact, be impractical for canals from which access of buffaloes could not be excluded. For major canals, in which such exclusion may be practical, soil cover would still be necessary to stabilize the lining against the forces of stream-flow. Vegetative growth rooted in the soil cover may then become a problem, either due to roots penetrating the plastic sheet or due to damage to the sheet during cleaning of vegetation. Damage during de-silting operations may be a further hazard. The use of plastic sheet as a single lining material is in fact restricted to special situations, generally relatively large canals, in which the necessary care in construction and maintenance can be assured.**

**The use of plastic sheet in conjunction with rigid linings is much more common and has considerable merit. The sheet may be regarded as the primary water barrier, the rigid lining providing mechanical protection, or as back-up to a rigid lining designed to be the primary barrier. Such composite linings may be applied to all categories of canal. The rigid linings for primary and secondary canals may be of cast-in-place concrete, pre-cast concrete panels slabs or tiles, brickwork or brick tiles, and stone slab or masonry. Continuously formed (slip-formed) concrete linings widely used in the western countries for canals of all categories are not generally employed in South Asia, probably because of difficulty in quality control. Concrete linings for major canals are either cast in place in panels of about 5 m width or are of pre-cast elements. The vulnerable point in either case is the joint.**

**It is not unusual to see heavy vegetative growth in joints between panels, and equally in the joints between pre-cast slabs, signalling leakage and the onset of**

**deterioration. While a plastic sheet behind such linings would nominally contain the leakage, it would not stop vegetative growth within the joint and would eventually suffer from root penetration of the sheet unless unusually heavy-gauge sheet was used. For cast-in-place panels, the most satisfactory solution is probably the extruded rubber or plastic joint sealing strip embedded in adjacent panels, traditionally used elsewhere. Externally-applied joint sealants, while continually being improved, do not yet provide this degree of security. For the smaller pre-cast slabs, accurately formed shaped edges providing inter-lock when mortared into place with back-up plastic sheet can be a satisfactory compromise. It will not stop capillary cracking at joints, but will prevent displacement of slabs and will inhibit establishment of vegetation in the joints. Vigilance is necessary in intercepting vegetative growth within the canal in the joints and behind the lining in the embankment. The problem currently is that slabs generally have very poor edge detail, partly due to poor gradation of aggregate and partly to the methods used in their production. This difficulty is not insuperable. However, the problem is often aggravated by the mistaken view that if a plastic sheet backing is used little attention need be paid to joints.**

**Brick work linings constructed before the turn of the century and still in good condition testify to the virtues of the material, if well-constructed. On the other hand many much more recently constructed brick linings have deteriorated badly. The primary problems are poor quality mortar and inadequate compaction of the fill on which the channel is built, resulting in differential settlement and cracking. The lime mortar used earlier was plastic in consistency, facilitating full imbedding of bricks, and had low shrinkage. The straight Portland cement/sand mortars currently in use, unless with very well graded sand, are likely to be harsh, non-plastic, and permeable. This again is a situation not without remedy. The use of**

**plastic sheet behind brick lining can contain the inevitable seepage through capillary cracks, but it should not be taken as an excuse for poor quality brickwork.**

## **Construction materials and production methods of tertiary canal linings**

**Tertiary canal linings may be made of the materials discussed above for primary and secondary canals, but being smaller also offer the possible use of integral (single-piece) pre-cast or preformed units. Such units one to two meters in length and placed end-to-end, comprise the whole "lining". It is more correctly a flume, as the units are structurally independent of support from the adjacent fill. Semi-circular or "half-round" spun cast units, lightly reinforced, are a typical example. Trapezoidal sections, produced in conventional molds, are also in use.**

**A new material recently installed on a pilot scale is G.R.C (glass reinforced mortar). This is similar in some respects to asbestos cement but the reinforcement, instead of asbestos, is alkali-resistant (zirconia-based) glass fibre. The material is sprayed on to a shaped mould, or alternatively on to a flat plastic sheet which is then draped over a mould. G.R.C has a number of desirable features including thinner section and much lighter weight than the equivalent concrete unit.**

**The critical item with all such integral linings is again the joint between units where movement occurs as a result of changes in temperature and moisture. A rigid jointing material such as the conventionally used cement mortar does not prevent such movement, and capillary cracking and leakage occur. A back-up plastic sheet can contain such leakage. However, elastomeric bitumens have been**

successfully used as flexible joint sealants, in a lap-joint configuration.

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  **Chapter 11 - Construction and maintenance problems of drainage works**

 **Drainage and the cultivator**

 **Formal and informal tertiary drainage systems**

 **Subsurface field drainage**

 **Primary and secondary drainage**

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**Chapter 11 - Construction and maintenance problems of drainage works**

**Drainage and the cultivator**

**Drainage channels are designed to remove surface water from fields and in some situations to lower the watertable by extraction of groundwater. While these are very desirable functions drainage channels can pose severe maintenance problems. Difficulties in maintenance of unlined canals previously discussed, including weed growth and encroachment by phreatophyte plants, are aggravated**

**in the case of drainage channels as ground conditions are usually wet year-round and vegetative growth can be prolific. Secondary and tertiary drains have an added problem. While cultivators reluctantly accept the disruption of access caused by the presence of irrigation channels, they are much less favorably disposed to secondary and tertiary drains. Tertiary drains, in particular, commonly exist on paper only, or are cultivated over within a year or two of construction. Secondary drainage channels, although nominally under Departmental jurisdiction, are often partially filled in by cultivators to provide crossings to fields or dwellings, or to provide ponds for small fish culture, such ponds usually being filled with water hyacinth and village debris.**

**The conclusion is that drainage channels should be limited to those which are essential, and that these should be adequately maintained and defended against encroachment. Provision of crossings, each with adequate culvert capacity, is essential, or obstruction by informal cultivator constructed crossings will inevitably result.**

### **Formal and informal tertiary drainage systems**

**The question of whether formal tertiary drains would survive in a particular project situation may be debatable, but the need for such drainage, in principle, is not. There should be a route for out-flow of surface water from every field, whether by formal drainage channel or otherwise. The alternative to a formal channel is flow via natural topographic features, i.e. by natural channels or depressions where they exist or simply down-slope across fields where they do not. Local excavation or land shaping may be required to ensure unimpeded drainage. This apparent disregard for the classic pattern of formal tertiary**

**drainage layout is explained by the realities of the South Asian smallholder situation.**

**Effective drainage must be provided at the tertiary level, but it must be sustainable, i.e. acceptable to cultivators as a permanent feature. Such acceptability will require provision of culvert crossings wherever drainage-ways intersect village roads or traditional bullock-cart routes. It is noted in this connection that introduction of irrigation into an area may double the annual run-off. Village roads, which in the course of time often become depressed below adjacent field level, may collect irrigation spill and become frequently impassable. The tertiary drainage system should intercept such run-off by construction of road-side ditches and regrading of roads where necessary.**

**The tertiary surface drainage system must be maintained by the cultivators as maintenance by the government agency would be impractical at this level. For this reason, the system must be designed in consultation with the cultivators. Furthermore, in situations where facilities not available to the cultivator are needed, such as additional culvert crossings or re-grading of a village road, the irrigation department should promptly cooperate.**

### **Subsurface field drainage**

**Due to its high cost, subsurface drainage, generally by perforated tube or tiles, is rarely employed in South Asian irrigation in view of its high cost, although there are large areas which offer no other alternative if full reclamation or development is to be achieved. The problem of the close spacing required for drainage of low permeability clay soils has been referred to earlier. Special situations do occur in**

**which the presence of an underlying horizon of more permeable material permits much wider spacing of pipe drains, in conjunction with vertical chimney drains extending down to the latter horizon. However, these situations are the exception. All other expedients should be explored before tube drainage is seriously considered, the expedients including lowering the watertable by restricting irrigation supply, by lining of irrigation canals, by groundwater development, or by changing land use to unirrigated tree plantations or to pond fishculture.**

### **Primary and secondary drainage**

**The function of the secondary and the primary drainage system is to act as an outfall for tertiary drainage. Nothing inhibits cultivator interest in maintaining tertiary drainage more quickly than having secondary/primary drainage channels back up and flood his fields, submerging the tertiary system. This may be inevitable in some circumstances, but it certainly should be exceptional.**

**The factors which determine the effectiveness of the primary/secondary drainage system are topography, wet-season water levels in the river into which the primary drains discharge, intensity of precipitation and rate of run-off from the area, and design and condition of maintenance of the primary/secondary system. Only the last item is controllable. Very high levels in the main river system, backing up water into the irrigated area, are not subject to manmade intervention unless by major upstream flood-mitigation storage. Extensive flood embankment construction and possibly major drainage pumping from behind embankments may be considered, but are outside the scope of the present discussion.**

**Very flat topographic gradients add to drainage design problems, requiring**



**relatively large channel sections. These can be calculated, however, provided that the rate of precipitation and run-off are known. These are the least predictable elements. No economically viable drainage system could accommodate a maximum possible storm. The task is to devise a primary drainage system whose cost is commensurate with the value of the agricultural production, or the physical facilities, which the system protects. This approach acknowledges that the capacity of the system will sometimes be exceeded and damage will result. The usual procedure is to decide upon a certain appropriate magnitude (and frequency) of storm and to design the drainage system to limit the period of inundation of crops during this event to a predetermined figure. It is emphasized that the occurrence of a more intense storm will result in longer period or greater depth of inundation of crops, and proportionate increase in loss of yield. This, however, is a marginal increase in loss. Of greater concern can be the damage to physical structures which may result from a storm greater than the "design storm", or greater rate of run-off than anticipated. A culvert through a railroad embankment may wash out, destroying the line, or breaching a main irrigation canal. Such structures should consequently be designed on much more conservative assumptions as to storm magnitude than in the case of agricultural damage. The incremental cost of providing additional capacity is local only, confined to the structure in question.**

**Frequently, a primary drainage channel has two separate functions, both influencing its design. The first relates to the outflow of the small but important amount of ground water seepage flowing into the secondary drains through much of the year. The key requirement here is to keep the bottom of the primary channel at as low a level as possible, as this level may control the elevation of the watertable in the area being drained by the secondary drains. The emphasis in**

**channel design from this viewpoint is on depth rather than capacity. The second function is evacuation of surface flows, either irrigation spill or more particularly runoff from heavy rainfall. In this case, the emphasis is on channel capacity, and bed elevation or channel depth are secondary considerations.**

**With regard to maintenance, both depth and width present particular problems. The wet ground conditions at the bottom of a drainage channel in which seepage water is flowing year-round promote heavy growth of phreatophyte plants, requiring frequent cleaning. In such situations an ideal, conceptual design would be a composite section with a relatively wide upper portion providing capacity for major storm run-off, and a central narrower, deeper, section providing for seepage outflow. This would minimize the extent of the perennially wet portion of the channel. An inverted near-triangular section can provide the same function, the apex being the narrow deeper portion of the water way.**

**If mechanical equipment is to be used for maintenance, the problem with channel width is the reach required, particularly if access is available from one side of the channel only. The equipment commonly employed is some type of hydraulically-operated back-hoe, either wheel or crawler-mounted. The reach of such equipment is dependent on its size and weight. Reach has recently been extended by the use of counter-weights, and by the introduction of an ingenious combination of cable and hydraulic actuation amounting to a combination of back-hoe and drag-line. However, there remain problems in procurement of appropriate equipment for drainage maintenance. A contributing factor is that all drainage channels are not of ideal cross section. Many are natural stream-channels, deepened or widened for project purposes. Such channels commonly meander through irregular terrain, are frequently joined by tributary streams which have to**

**be crossed, and are distant from roads. Equipment required in such circumstances should be capable of off-road travel in difficult and often very soft ground conditions. It should also be capable of travel on conventional roads, preferably without the use of transporter. Finally, it should have longer-reach capability than currently provided with medium-capacity back-hoes. Equipment meeting these requirements is not yet commercially available, although it is within the capability of manufacturers.**

**An issue in some main drainage systems is whether to permit alternative uses of the channel in the non-flood season. This includes pondage of water for fish culture or small scale lift irrigation of specialty crops (usually vegetables) adjacent to the channel. In other circumstances, the channel is made shallow and wide, and is used for cultivation of paddy or of "floating" rice in the wet season, the crop being temporarily inundated during flood-flows. Against such practices it can be argued that it is difficult enough to prevent obstruction of drainage channels without officially encouraging it. However, provided that the level in the channel does not have to be held down in the non-flood season for watertable control there is no technical reason why the alternative use should not be permitted. In any case it is likely to be practiced unofficially. Such use could be more effective if formal bottom-weirs were installed, closed for impoundment of water in the dry season and opened for unimpeded flow in the wet.**

**A related practice which has been developed on a pilot scale, in secondary drains, amounts to organic control of phreatophytes, particularly a variety of bull-rushes (typha) which is particularly troublesome in many area. Typha can be displaced by pare-grass, a virile plant which grows well in a wet environment forming long trailing stems which may be harvested for cattle-feed. Harvesting is accomplished**

**simply by pulling on the stems from the bank, the stems breaking at lower nodes. Such a practice requires organization to ensure that the drainage channel is reasonably clear of pare-grass during the wet season, when its capacity is needed for drainage outflow. Typha may also be displaced by rice, the plant being sensitive to a toxic compound produced in the root system of the rice. However, conditions in the drainage channel must be maintained favorable to rice cultivation.**

**A very difficult drainage channel maintenance situation is encountered in some highly erosible clay soils. It is almost impossible to maintain a conventional channel section in such soils due to rapid erosion of the channel side-slopes in heavy rainfall. One expedient is to line the channel. This, however, also poses problems as the clays are expansive, a difficulty which can only be overcome by over-excavation and back-filling with non-expansive material prior to lining, a costly procedure for drainage channel construction.**

**A final example of difficult drainage is the problem of "quick" conditions, in which a channel excavation is rapidly refilled by upward flow of material from the bed. The conditions make either open drainage or closed (pipe) conveyor very problematical. The situation usually occurs in low-lying perennially wet areas, fortunately usually local. A solution consistent with modern environmental views could be to reclassify such a location from a drainage problem area to an ecologically valuable wet-land, and to leave it untouched.**







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## **Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)**

### **Chapter 12 - Cultivator organizations**

-  **Cultivator organizations in irrigation system operation**
-  **Traditional organization in village-level irrigation schemes**
-  **Projection from the village-level organization to cultivator organizations in public systems**
-  **Experience and problems with water user groups in public irrigation systems**

## **Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)**

### **Chapter 12 - Cultivator organizations**

#### **Cultivator organizations in irrigation system operation**

**The degree of flexibility provided in operation of the canal supply system and the level down to which supply can be matched to demand have been discussed earlier. In schemes which have limited storage regulation, or none, variations in supply to the canal system are largely externally imposed. On the other hand where there is a high degree of storage regulation, variations in supply to the system can be largely controlled. Delivery to the tertiary in either case is generally regulated through pre-arranged schedules, subject to availability of water.**

**Within the tertiary command itself delivery to the individual farm can also be**

**strictly in accordance with a established rotation, or it may be modified to suit individual needs. In a scheme in which supply to the canal system is highly regulated and predictable, and in which delivery to the individual farmer is strictly in accordance with a fixed schedule, the need for cultivator organization is minimal, other than for communal maintenance activities and general policing of the tertiary system. However, in schemes where supply is less predictable, requiring frequent changes in rotational deliveries within the tertiary or where effort is made to meet the water needs of the individual cultivator by modification of rotations, some degree of cultivator organization is necessary. Such day to day operational modifications within the tertiary command could not be effectively managed by irrigation department staff.**

**Whether or not cultivator organizations have a part to play outside of the tertiary command, for instance in management of operation of the secondary canal, may be debated. But within the tertiary command, such organizations are often essential. The issues are how effectively they operate, and what assistance they may need to become more effective. To date their performance in major public irrigation systems has been mixed (Sunder 1990).**

### **Traditional organization in village-level irrigation schemes**

**In village-level schemes, particularly small "tank" systems, organization of irrigation distribution is generally remarkably efficient. Many of the schemes were constructed back in the days when village authority was absolute, and cultivators held their land under sufferance to the local ruler. Progressive weakening of traditional authoritarian structure and substitution by democratic process is changing the situation rapidly in some areas, but operation of village schemes**

**remains reasonably effective. The method of operation varies, but generally an individual is delegated the task of operating all structures including turn-outs to each farm. He is paid by, and under the direction of, the cultivator group. In some cases, however, the post is inherited and carries considerable authority. Sharing of the tasks of maintaining the system is also well organized.**

## **Projection from the village-level organization to cultivator organizations in public systems**

**A question frequently asked is if the organization of village-level schemes works so well why is it so difficult to obtain effective operation of tertiary-level water user groups in larger public irrigation systems? The answer lies partly in the attitude of cultivators to government facilities, in contrast to village-owned facilities. The philosophy that if government built it then government should operate and maintain it is deeply rooted. In the eyes of the cultivator the government label still remains, however sincere efforts may be to involve cultivators in all stages of planning and construction of a facility, . This is very evident, incidentally, where government assistance in rehabilitation of tank schemes can have the unfortunate effect of causing villagers to abdicate responsibility for operation and maintenance of a previously well managed village scheme.**

**There are other factors contributing to the problems of group operation at the tertiary level. The supply to the tertiary is indeed under the irrigation department's control, and the cultivator view is understandably that any deficiency in supply is due to government mismanagement. He will consequently take whatever water he can get, as an individual, without regard for the interests**

**of his neighbors or the group as a whole. There has been much discussion of the merits of including representatives from water user groups in the management of water releases at the primary and secondary canal level, largely to avoid this problem. But such interaction between cultivators and the irrigation department is not yet common. In any case, the scope of such cooperation would necessarily be limited operationally, as the interests of individual tertiary commands may well be mutually in conflict. Moving the scale of water user group management from the individual tertiary command up to the secondary canal command (ten to twenty or more tertiaries) has also been suggested.**

**A further distinction between a village scheme and a tertiary command of a public scheme lies in the social situation within the two. While the group served by a village scheme may cover the whole social spectrum, communal relationships with respect to water distribution have been established in the village over several generations. In the case of a tertiary command in a newly developed irrigation area, the group has been brought together for the first time, as far as any type of communal activity is concerned. Substantial differences in caste, ethnicity or the level of economic affluence may well exist within the group. The bond of a common water source may bring such a disparate group together eventually, as it has with the village scheme, but close cooperation cannot be expected immediately.**

### **Experience and problems with water user groups in public irrigation systems**

**Much effort has been devoted to the organization of irrigator groups in South Asia over the last two decades. It has been a principal area of interest of national and international institutions associated with irrigation development in that region.**



**Water User Groups are operating very effectively in some areas, and very poorly or not at all in others. The differences can be accounted for partly by cultural factors, there being stronger traditions of collective action in some communities than in others. Another factor is the nature of the irrigation supply, its regularity and its importance in relation to rainfall. Where the supply is reasonably predictable and its distribution within the tertiary command is regulated by long-established well-accepted rules, there is little need for formal organization of water users other than for maintenance of the tertiary channel system. On the other hand, where irrigation distribution is complicated by less predictable supply or where it is supplemental to variable rainfall, there is greater need for cooperation between cultivators within the tertiary command with regard to management of irrigation deliveries. Unfortunately, these are also the circumstances which put most strain on the group. To illustrate, if cultivators have planted in anticipation of normal seasonal rains plus regular supply of supplemental irrigation, only to encounter abnormally low rainfall coupled with less than usual irrigation supply, they are unlikely to conform to group decisions regarding sharing the deficiency, however rational such decisions may be. Faced with serious crop loss each individual is likely to take what irrigation he can get, with consequent breakdown of the group and of the tertiary rotation. Breakdown of the rotation may also occur in the wet season if the primary crop is paddy. Irrigation distribution by continuous small flow to each holding may be more convenient to the cultivator than rotational supply, and in most respects may be equally effective. Such a departure from rotation in the wet season may not be of consequence except for the difficulty of reinstating rotation in the dry season, when it is essential. Aside from stresses imposed on group operation by external factors such as deficiencies in supply, there may be internal problems, political**

**and social. A socially or economically powerful individual or sub-group may unduly influence the functioning of a water user group, to the disadvantage of those of lesser standing.**

**In spite of the difficulties which have been experienced with water user groups, they are regarded as vital to effective operation of smallholder irrigation systems in many situations. The key question is how assistance may best be provided in their establishment and operation, without detracting from their essential autonomy (Byrnes 1992).**

**In designing an irrigation system, it is not sufficient to simply stipulate the formation of water user groups, if such are required. The necessary support for group formation and assistance with and monitoring of their operation should also be included as essential project components.**



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 **Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)**

  **Chapter 13 - Village schemes and small tank projects**

 **Background**

 **Farmer-constructed diversion systems**

 **Village schemes with storage**



## **Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)**

### **Chapter 13 - Village schemes and small tank projects**

#### **Background**

**While major public projects, notably those dependent on diversion from major river systems, make up the largest component of irrigation in some regions, elsewhere small schemes provide the greater part of canal irrigation. The area served by individual small schemes range from less than 50 ha to as much 5000 ha, but are generally a few hundreds of hectares. Where a scheme is based on direct diversion from a stream, without storage, construction and operation, in the past, has generally been entirely by the participating farmers. On the other hand where, a small reservoir is involved, as in the "tank" common in India, Sri Lanka and elsewhere, construction is commonly by state agency, with the state also being involved in some cases in operation, although generally to a limited degree. Included in the direct diversion systems are the notable "hill" schemes of Nepal.**

**Although these were originally entirely farmer-constructed, government agencies are now providing assistance in rehabilitation, and are involved in construction of new projects. The manner in which this assistance should be provided and its impact on the previously autonomous character of the hill schemes are much debated.**

**In view of the attention currently being paid to the ecological costs of major storage projects, international development agencies have increasingly turned to small schemes, particularly those which enlist cultivators in their construction and management. It is noted, however, that although such schemes are conceptually very appropriate from the development point of view, their implementation poses a number of problems, some of which are referred to in the following discussion.**

### **Farmer-constructed diversion systems**

**These commonly consist of a low weir, often requiring renewal after each high-flow season, a conveyance canal leading to the area to be irrigated, and distribution channels within that area. Much ingenuity and a great deal of labor have gone into construction of these works, and considerable labor is required in the annual task of reconstructing or repairing the diversion weir. The weir may be made of brush-wood and cobbles, or many rows of wooden stakes driven into the river-bed where it is of soft material, and infilled with mud. More recently wire mesh baskets filled with cobbles (gabions) are being used for weir construction, where stones of suitable size are available.**

**Such systems are exposed to a number of hazards. The diversion weir may be washed out during the irrigation season by a late flood, or the conveyance canal**

**may be put out of service by slides (particularly in the very steep terrain of the hill schemes). In a dry year the stream-flow at the diversion may be excessively small. Many such schemes are on streams which normally cease flowing entirely early in the dry season (i.e. are non-perennial), in which case irrigation is confined to supplemental watering in the wet season and supply to a limited portion of the service area early in the dry. Others are on perennial streams, but usually with dry-season flow highly variable from year to year. In these circumstances, the extent of the area which can be irrigated in any particular year is uncertain, and farmers at the tailend of the distribution systems are likely to have very precarious supply. However, experience over the years indicates how far the distribution system can usefully be extended, granted that returns from the lower end of the system may be marginal.**

**Conventional economic analyses did not, of course, enter into the design of the existing farmer constructed schemes. They were constructed at a time when there was little avenue for other employment (low "opportunity cost" labor). In a subsistence-level situation even uncertain irrigation supply was judged to be better than none. This is obviously not an adequate basis for analyses of such a scheme from the viewpoint of an international development agency. The entry of such agencies into the field of the small farmer system poses a number of questions. These include the scope of the assistance, whether improvement of existing schemes or construction of new schemes, whether there are, in fact, many perennial streams suitable for development which are not already preempted by existing schemes, and what economic criteria should be used in determining the viability of new schemes (undeveloped sites are often undeveloped for the reason that they are problem sites and thus costly). In terms of the criteria usually employed in evaluation of irrigation projects many schemes**

**on small unregulated nonperennial streams would be judged non-viable. However, in the development of such small schemes there can be important socio-economic factors which lie outside the compass of conventional economic evaluation of larger irrigation projects (such as, in the case of hill projects, the alternate cost of transport of food into remote areas without road access, or the social cost of migration from such areas). In any case, it would be impractical to analyze in detail each scheme as small as two or three hundred hectares, and simplified economic criteria have to be devised. The nature of these criteria strongly influences the scope for participation of international financing agencies in village-level irrigation development (Martin 1987, Sundar 1990).**

**In addition to the economic criteria, the irrigation system design approach needs to be tailored to the particular situation of the village scheme. The development in most cases is likely to be improvement or extension to existing schemes, and the concept of farmer ownership must be preserved at all costs. The improvements should be primarily those requested by the farmers, i.e. works aimed at remedying problems perceived by the farmers rather than those conceived by the lending agency as being desirable. This approach is doubly necessary if the farmers are to be asked to pay for or contribute to the work. However, it is reasonable to expect that the lending agency would wish to see some degree of up-grading as the result of its participation. In this regard, there are modern technologies which could indeed be introduced with considerable benefit, provided that farmers were persuaded of their value. Such technologies must, however, be adapted to the particular circumstances of such schemes, notably maximum use of local materials, minimum transportation (particularly in remote hill projects), and minimum cost to the farmers concerned. These requirements will often rule out designs which are scaled-down versions of structures conventionally used in**

## **larger projects.**

**In cases where the proposed improvements to an existing scheme go beyond the construction of a more permanent intake weir and include reconstruction and possible partial lining of the conveyance canal, an issue may be whether the size of the service area should be reexamined, particularly in the context of increased canal capacity. Any such reexamination poses two questions. First whether the crops currently grown are indeed appropriate to the site, and second whether the cultivators would agree to any change (these are "farmer-owned" schemes). For example, in Nepalese hill projects, paddy, the favored crop, is being grown in soils with infiltration rates many times higher than the rate normally considered to be the appropriate upper limit. Hence, should the improved scheme still cater to such service, or should a change in cropping pattern be suggested and if so to what alternative crops. If the cultivators being served by the scheme strongly prefer to stay with rice, as is likely to be the case, should a change from wet-land practice to up-land be suggested (much of the rice at present being grown in such areas is in fact grown largely under up-land conditions). The problem is that any reduction in supply of water to existing irrigators, in the interests of supply to others, is likely to be resisted by the present irrigators, whose rights may be of long standing. Furthermore, any increase in consumptive diversion to one scheme may reduce the flow available to some downstream scheme. It is evident that the approach to irrigation system design in a small hill scheme may be very different from the approach to the design of a major scheme. A case by case approach is necessary, with as much attention to sociological as to technical factors.**

**With regard to technical design, the possibility of introducing newer materials and methods into the traditional construction of small schemes is worth consideration**

**and is attractive to international lending agencies assisting in this area. Possible improvements to intakes (a perennial problem to farmers) include greater use of wire-mesh stone-filled crib work, and particularly the use of cribs fabricated from light steel rod rather than wire to better withstand abrasion by rocks during passage of floods in a mountain stream. Tethered boulders, retained by steel rods with upstream anchorage have been used elsewhere in weir construction in torrential streams, and would appear attractive for hill schemes in some situations. Improvements to channel linings by incorporating modern geotextile fabrics behind traditional masonry lining also offers possibilities, and in some locations the use of light-weight portable prefabricated channel lining units constructed of G.R.C. (fiber-glass reinforced mortar).**

**The design of improvements to an existing small scheme or the design of a new one is not necessarily simple. All of the physical factors entering into the design of a larger project are present in the smaller scheme, but with diseconomies of scale. Indeed, more engineering judgement may be required in the design of improvements to a small scheme than in the more conventional text book design of a larger one. In addition, much of the topographic and hydrologic data normally available in the case of the larger project may not be available in the case of the small schemes. Added to the problem is the difficulty of access to the small scheme (commonly several days on foot in hill schemes) for staff carrying out investigation, design and technical supervision of construction.**

**Important issues are the extent to which work on small schemes should be carried out by the beneficiary farmers versus by contractor, responsibility for supervision of construction and disbursement of funds, and the respective roles of the national agencies which may be concerned (Irrigation, Agriculture, Rural Development,**



**etc.)**

**Small farmer-constructed diversion schemes are undoubtedly an important component of agricultural development in some areas, and one which deserves the support of international development institutions. However, any direct involvement (other than simply financial support to concerned national agencies) must face a number of issues which have proved troublesome in the past and are likely to limit the scope for channeling financial assistance in this direction.**

### **Village schemes with storage**

**In view of the highly seasonal nature of rainfall in monsoonal regions, any irrigation scheme would benefit from reservoir storage, including small village schemes. However, construction of even a small storage (usually referred to as a "tank") is usually beyond the capacity of a farmer group and involves the participation of government agency. The farmers served by the system usually operate and maintain it, with minimum further government intervention. There are large numbers of such schemes in existence, some centuries old. The area served ranges from as little as fifty up to several thousand hectares. New construction of tanks continues and tank rehabilitation programs are also in progress.**

**The tank scheme has all the ingredients of a highly desirable field for participation of international financing agencies. It has a considerable element of self-help and farmer management, it is ecologically sound, and it undoubtedly improves quality of life in the village. Factors influencing the scope for further development of such schemes include the availability of sites suitable for storage construction and a number of financial and economic issues.**

**With regard to sites, key considerations are topography, which determines the cost of storage capacity, and hydrology. A typical location is in an open valley, combining the possibility of obtaining storage capacity at relatively modest cost of dam construction and a service area immediately downstream from the dam, partly in valley-bottom and partly on the valley slopes. Alternatively the reservoir may be located in the more steeply sloping head reaches of the valley, a supply canal extending down to a service area in the more gently sloping lower reaches.**

**The hydrology of a site is of interest in two respects, yield and flood flow. As there are rarely river-flow or rainfall records of long standing at small project sites, the estimation of seasonal yield and of flood-flow are likely to be quite approximate, as evidenced by the number of existing tanks which have never filled and others which have over-topped due to inadequate spillway capacity. There is need for further study of the hydrology of small catchments in semiarid areas and further installation of hydrological and meteorological recording stations in areas of prospective further tank development.**

**The spillway is often the major item of cost in a small tank scheme, particularly where several such schemes occur in series, down the length of a valley. The yield available to each of the schemes is then only a proportion of the total yield from the catchment, but the flood flow which has to be accommodated at each is the whole flood from the catchment, subject only to the small amount of flood regulation in upstream tanks. This can lead to disproportionately high spillway costs per unit of area irrigated, particularly for very small schemes. The problem is aggravated by the fact that conventional design requires founding the spillway and its outlet channel and terminal energy dissipating structures on sound rock, which is often at considerable depth in the topography common to small tank schemes.**

**There is room for a less conventional approach to the design of small tank spillways, including greater use of flexible stone-filled wiremesh crib-work, which reduces the need for founding on bed-rock and the various means of protecting small embankment dams against wash-out in the event of overtopping, currently receiving considerable attention elsewhere.**

**The long-term hazard with small tanks is siltation. Many older tanks are operating at much reduced capacity or are virtually out of service, due to depletion of storage capacity by silt accumulation. Removal of silt from existing tanks by mechanical excavation is of doubtful economic viability. In some cases the storage capacity lost by siltation can be compensated by raising the crest of the dam, but only where the higher reservoir level would not present a problem of encroachment. The use of some form of automatic spillway gate, limiting the surcharge on the spillway crest during passage of floods, can convert flood surcharge pondage to active pondage, thereby increasing net storage capacity. The gates can be hinged wooden shutters arranged to fall, or to tilt, when the reservoir reaches a certain level. The shutters are reset after passage of the flood. More sophisticated automatic shutters are available, which conserve part of the flood volume, but sophistication is not a desirable feature in a small tank with minimum maintenance and maximum exposure to interference with the spillway structure. Increasing the effective length of the spillway crest by employing, in principle, the duck-bill weir arrangement previously described (the crest in this case has a zig-zig configuration, in plan) can also reduce the height of flood-rise, thereby increasing live storage capacity.**

**Reducing the rate of siltation is of course highly desirable, although not generally easy to accomplish. The catchment area may be cultivated lands, with high**

**sediment run-off when heavy monsoon rains fall on newly ploughed fields or it may be in over-grazed deforested lands also subject to heavy run-off. Anti-erosion measures are available, but generally involve changes in land use or cultivation practices in the catchment area, raising questions of jurisdiction and recovery of cost. Much of the catchment erosion is commonly focused on local areas, such as deeply incised stream channels which are back-eroding in soft material. Remedial measures may be initially directed at such areas, which do not raise the problems of changing land use or cultivation practices. A more comprehensive method of erosion control involving contour planting of vetiver grass is being promoted by the World Bank. It has been particularly successful in some areas.**

**The concept of conserving excess monsoonal runoff at source, in a multiplicity of small pondages, is very attractive ecologically. The storage may be as small as farm ponds, the somewhat larger "seepage tanks" which serve solely to recharge groundwater for supply to immediately downstream dug-wells, or the regular irrigation tanks with associated small canal systems. Construction of farm ponds can be undertaken by the cultivator himself. The spillway problem is minimized due to the very small size of the catchment involved, the whole storm runoff generally being accommodated in the pondage. Alternatively, a simple spillway channel, protected by appropriate vegetative cover, may be provided. The hydraulic head involved is small, and erosion during flood discharge is not a major consideration, nor is the stability of the very small embankment dam.**

**However, in moving up the scale to the conventional small tank the situation changes. Construction of an embankment dam by manual methods (head-basket or bullock-cart) is in some respects an excellent village enterprise, particularly during periods of "scarcity" when there is little alternative employment. However,**

**many such dams have failed due to slides on the upstream or downstream slopes because of design deficiencies, unfortunate choice of fill material, or lack of compaction. Such incidents can be avoided by providing appropriate technical assistance to the villagers concerned, also with respect to spillway provision.**

**From the viewpoint of the international agency, a key issue in the construction of tank irrigation schemes is economic viability. This problem has already been discussed in relation to small direct diversion schemes. In the case of a tank scheme the availability of water storage permits higher crop benefits, but adds considerably to construction costs, particularly due to spillway works. Conventional economic analysis based on conventional cropping patterns, as would be applied to a major irrigation project, frequently indicates that a prospective small tank scheme is economically non-viable. However, such simple analysis does not do justice to the full range of benefits of a tank scheme. Particularly in a semi-arid area, a tank scheme is a catalyst for many village activities, often effecting a remarkable transformation from the pre-project condition. While the "quality of life" aspect of a tank scheme in such an area should not be ignored, such benefits are not readily evaluated in economic terms. There are much more tangible benefits which can and should be evaluated, in deciding the fate of a prospective tank scheme. The deficiency may not be in the scheme, but in the scope of the economic analysis.**



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**Design and Operation of Smallholder Irrigation in South**



## Asia (WB, 1995, 134 p.)

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## Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)

### Chapter 14 - Groundwater development

#### Introduction

**Where alluvial aquifers are available, such as in the Gangetic and Indus basins, groundwater can make a major contribution to irrigated agricultural production. In areas underlain by hard rock the potential for irrigation by groundwater is much less, but is still an important factor. A key question that is much debated in such development is the role of the small farmer-owned tubewell versus group-owned medium sized wells and larger public wells.**

**In areas where ground conditions permit its use, the small well can be very attractive, both to the small farmer proprietor, as it provides a supply of water virtually on demand, and to the government, providing development with little drain on national financial resources. There are, however, physical situations in which the small well cannot operate, due to technical reasons that will be discussed below.**

**More relevant to the present discussion is the situation in which small wells have been operating reasonably satisfactorily for some time, but continued unregulated installation is drawing the dryseason watertable down to the physical limit for such "suction-mode" wells. Dry-season supply at the individual well becomes unreliable, and groundwater extraction becomes competitive. Some well owners construct pits at the well-head, lowering the pump 2 or 3 m below ground surface, thereby increasing the depth to watertable at which they can operate. Larger farmers or farmer groups in some areas install "force-mode" pumps which do not have a depth-to-water/able limitation, further aggravating the problem for the small well owner who cannot afford such a pump.**

**It can be argued that such a situation could be prevented by appropriate regulation, but in the South Asian region efforts to control groundwater development, largely confined to withholding of credit for new installations, have been largely unsuccessful. On the other hand, it can also be argued that full development of the resources of the aquifer, including utilization of its storage capacity by deeper draw-down in dry years, can only be accomplished with the use of force mode pumps.**

**A pressing question is the fate of the small farmer where installation of force-**

**mode pumps by larger farmers is occurring on a significant scale and is leaving the small farmer with a dry well in the critical irrigation season. Over time a water market may develop, in which larger farmers with force-mode pumps sell water to neighboring smaller farmers (Shah 1989). The process may, however, take a long time, leaving many small farmers in distress. One possible course is to form groups of small farmers to share in the ownership and operation of force-mode wells. As the construction of such a well and installation of the pumping equipment is a considerably more sophisticated task than in the case of a simple suction-mode well, at a minimum technical assistance by a government agency is likely to be required. The well could be owned and operated by the group or owned and maintained by government agency, with the group being responsible for its operation.**

**However, the involvement of a government agency in construction of such wells, in an area already largely developed or overdeveloped by small wells, can introduce problems of equity (Toulmin 1987). There is seldom sufficient recharge to effectively irrigate more than one-third to one-half of the surface area. Where almost every farm has a small well, or access to one, a portion only of each farm is irrigated. With such density of wells the cost of distribution of water is not a factor. The position is substantially different with medium capacity force-mode wells which are spaced farther apart, and in which distribution is a significant item of cost. The logical economic solution is to supply water to an area in the vicinity of the wells, and to leave the intervening area unirrigated. However, farmers in the latter area who previously obtained limited supply from their small wells would be left without water in the dry season due to draw-down of the watertable by the adjacent medium wells.**



**In the broad perspective of effective utilization of the aquifer, the installation of force-mode medium wells may be desirable, and it may eventually occur through the initiative of the large cultivators. However, it can result in hardship to those left outside the service areas of the medium wells. This is a problem with no entirely satisfactory solution. Installation of medium wells with relatively large service area and correspondingly low irrigation intensity reduces the proportion of the area without groundwater supply, although at considerable cost in distribution system. This course is also likely to result in some discontent among cultivators served by a well, due to the limited supply of water to the individual. However, where groundwater is being utilized in association with largely rainfed monsoonal cropping, and where cultivators are paying the full cost of pumping, it is remarkable how economically such water is used. Perennial crops that are heavy water users, such as sugarcane, are ruled out in these circumstances, except for the large farmer who has his own well.**

**The remainder of this section is devoted to a brief account of the technology and application of small suction-mode wells, group operated medium-capacity force-mode wells, and larger forcemode wells that are either operated by public agency or by farmer groups.**

### **Small, individually-owned, suction-mode wells**

**These wells are characterized by a pump located at ground level or in a shallow pit. Water is lifted to the surface by suction, and hence the lift is limited to the barometric height. In fact, for practical purposes it is limited to six or seven meters. The pump is a single-stage centrifugal, usually direct coupled to a small diesel or kerosine engine of 4 or 5 hp or to an electric motor, if electric power is**

**available. The well itself (the term "well" is used interchangeably for the tubewell or for the complete installation including the pump) generally consists of a steel pipe about 10 cm in diameter with perforated lower end sunken into the ground a distance of typically 20 or 30 m. Slightly more sophisticated wells are constructed with a filter, often of coconut fiber, surrounding the perforated portion of the pipe.**

**Well-sinking is generally carried out by a small local contractor using a variety of indigenous methods. The yield is commonly 10 to 15 liters/sec (1/3 to 1/2 ft<sup>3</sup>/sec). Where the pump is driven by a diesel or kerosine engine, it may be permanently connected to a well, or alternatively it may be moved from one well to another (a "taxi" pump) so that four or five wells are served by the same pump. The life-span of a well is only a few years, the well being reconstructed when the need is indicated by diminished yield. In hard-rock areas the equivalent of the small tubewell is the dug-well, several meters in diameter and usually some 10 or 15 m in depth. The dug-well may be supplemented by holes drilled from the bottom of the well to increase yield. The same type of suction-mode pump is employed as described above.**

**A small tubewell with yield of 10 liters/sec. could supply an area of 5 or 6 ha, subject to available recharge. However, the area served is generally one or two hectares only, part of which may be by sale of water to neighbors.**

**The primary feature of small section-mode wells which has made them very popular in the past is their low cost, which permits a cultivator with a modest sized holding to have his independent supply and possibly to sell a limited amount of surplus water. Purchase of water has also brought the benefit of such wells within the range of the smaller cultivator who could not afford his own well, or**

**when his holding is too fractionated to make ownership practical.**

**The applicability of such wells is limited by technical and socio-economic factors. Technical factors include a dry-season watertable within the suction limit, a suitable aquifer at depth reachable by low-cost well-sinking methods, and sufficient recharge. The socio-economic factors refer to the size of the holding and particularly to the degree of fractionation. A cultivator with a 1 ha holding made up of five parcels in separate locations, each of less than one-quarter hectare, could not be a candidate for a well, unless based on sale of water. The notable slow-down of the rate of installation of small wells in the eastern Gangetic basin in recent years has probably been due to the fact that most cultivators with sufficient size of holdings already have wells. The remaining cultivators have holdings too small or too fractionated to justify investment in a well.**

**With regard to recharge, in a monsoonal region the primary source is seepage from rainfall. Seepage from irrigated fields and from canals may also contribute. As indicated earlier, the amount of annual recharge is generally sufficient to provide irrigation to about one-third of the area, but varies considerably with amount of rainfall and soil infiltration rate.**

**The main constraint on the use of small suction-mode wells is undoubtedly depth to dry-season watertable and lowering of the watertable either by over development or by introduction of forcemode wells.**

**Individually owned and group owned force-mode wells**

**In the force-mode well, the pump is located at the lower end of the tubewell**

**rather than at ground surface, and water flows up the well under pressure, rather than being drawn up by suction. Thus, there is no physical limit to the height of lift, or the depth of watertable, against which the pump can operate. The pump itself is the generally the same as the surface-mounted centrifugal, but due to the space constraints at the bottom of the tubewell, the pump is smaller in diameter. It is usually made up of a number of units operating in series, rather than a single impeller, to give the required pressure. The engine may be at ground surface and connected to the pump by a long hollow shaft extending down the length of the tubewell, with guide bearings at intervals. In the case of electrically operated pumps an option is to have a submersible electric motor directly coupled to the pump at the bottom of the well, with power cable leading to the surface.**

**Other types of force-mode pumps include the hydraulic jet pump, the helical rotor pump, the hydraulically driven turbine pump, compressed air "pumping" and positive displacement units including the reciprocating pump. The latter is used extensively, usually hand-operated, for domestic water supply, but the yield is too small to be used for irrigation other than for small household plots. Effectively, the options available are long-shaft centrifugal pumps, either diesel or electrically driven or electrically driven submersible-motor pumps. Where electric power is available, the submersible-motor pump is attractive, particularly for smaller-capacity units. It avoids the long shaft and supporting bearings, with attendant problems of installation and maintenance.**

**A key question regarding the application of submersibles to the installation of force-mode wells by individuals or small groups is their minimum practical capacity. Recent advances in the use of high-technology plastics and composites, and in manufacturing methods, have lowered both minimum capacity and cost.**

**Facilities for servicing such units are also becoming available in irrigation areas. As a consequence, small submersible force-mode pumps are coming increasingly within the reach of the large individual cultivator. For the small cultivator, group operation of such units, or purchase of water, are likely to remain the available option.**

**It is noted that with the wells under discussion, generally capable of serving 10 to 15 ha or more, there is not only the well to be considered but also the distribution system. With a small well serving 1 or 2 ha distribution of water is not an important factor, as the length of run from well to farthest plot is unlikely to be more than 150 m, which is well within the range of an unlined channel. However, when the area served is 15 to 20 ha the length of run is likely to be 400 m or more, and seepage losses in distribution could be high. In this case the economic installation may be a well plus a partially lined (or buried pipe) distribution system.**

**There are advantages and disadvantages in group ownership or group operation of a well. Supply from a well owned by a group is presumably more secure than purchase of water, which may not always be available from a supplier. Further, in an area in which tubewell irrigation is newly coming into use, there may not yet be a developed water market, and group ownership may be the only option. However, group ownership and operation can have its problems, including allocation of responsibility for equipment maintenance and repairs, procurement of fuel and lubricants, payment for energy, and conflict resolution over for scheduling the use of the well. Experience in some areas indicates that once a water market has developed groups tend to break up, some members preferring to avoid the responsibilities of ownership by buying water from others (Shah 1987,**

**Toulmin 1987).**

**Experience with joint ownership of wells, other than small suction-mode wells, has in fact been decidedly mixed. Part of the reason is the size of the area served and the number of cultivators involved. While a group-owned small well supplying 2 or 3 ha may typically serve five or six cultivators, often related to each other, a "medium" force-mode well is capable of serving a considerably larger group of forty or fifty cultivators or more, and indeed it needs to, if costs to the individual members are to be minimized. Obtaining agreement of all members of such the group to undertake the joint enterprise and accept financial responsibility is not easy. Subsequent collection of funds for day to day running expenses and for repairs in the event of major breakdown or replacement of equipment is also likely to be a problem for the group.**

**First preference of small cultivators is usually for government ownership and operation, usually implying subsidized rates and no capital obligation. This is obviously not a desirable solution from government viewpoint, as it requires not only large initial outlay but also continued funding of a substantial proportion of energy costs. However, in negotiating a compromise solution, the cultivator has the option of simply continuing with rainfed cultivation. With this no cost alternative available to the cultivator, the less enterprising cultivators are unlikely to be willing to assume capital obligations or the responsibility for operation and maintenance. The more enterprising might be willing to do so, but group formation is a voluntary process and requires consensus among those in the prospective service area.**

**In an effort to make group operation more attractive to cultivators, a number of**

**compromises have been suggested, notably making available to the cultivator group the well and equipment at no cost and giving responsibility for running it to the cultivators, including meeting the cost of fuel or power. The reason for this course is simply expediency, rather than economic logic, there being no other way to obtain cultivator participation. However, in support of the cultivator view, it must be admitted that the government seldom attempts to recover any of the capital cost of providing canal irrigation, which is usually considerably greater per hectare served than the capital cost of tubewell irrigation.**

**There is, however, another factor which may deter cultivators from owning a medium well system, even if it is provided to them at no capital cost. This is the threat of major maintenance. Where a force-mode pump is required, which is the situation being discussed, both the tubewell and the pump are more sophisticated than in the case of the suction-mode well traditionally employed by small cultivators. The pump requires specialist attention in maintenance or repair. The tubewell itself may be in a difficult fine-grained aquifer with possibility of sand-pumping and eventual collapse of the formation around the screen and well failure. This situation requires sinking a new well. If cultivators have witnessed the problems of government agency in such circumstances, they are likely to prefer to leave ownership and major maintenance of well and pump in the hands of government, which has substantially greater financial and better technical resources.**

**The functions which government agencies would most wish to transfer to the cultivator group are in fact neither capital repayment nor major maintenance. They are the day-to-day operation of the well including scheduling of deliveries to individual members of the group, both of which require the services of a tubewell**

**operator, the collection of water charges and payment of all fuel or energy costs. These are functions which the cultivator group can probably perform better than government agency. Energy costs and the salary of the tubewell operator (which can be as much as the cost of energy) are a continuing drain on government financial resources if wells are fully operated by the government, and water charges are inadequate to cover running costs (which is usually the case).**

**With regard to the process of group formation, it is noted that negotiation of a firm commitment to take water prior to construction of a well, although desirable, is not always possible, as the yield from a particular well and the size of the area which can be served by it may not be known until well construction is completed and yield tests carried out. This is commonly the case where the character of the aquifer is highly variable. This situation of constructing a well before final commitment by prospective users puts the constructing agency at some disadvantage in negotiation, and underlines the need for the cost sharing arrangement to be reasonably attractive to the potential group members. The process of group formation including consultation with prospective participants at all stages in the investigation and construction of a well is a key element in successful group operation of such wells.**

**To summarize, group ownership of a small suction-mode well serving a small group of neighbors, does not present a problem. However, where depth to watertable or the character of the aquifer preclude the use of such pumps and a force-mode pump has to be employed, generally with larger capacity well and considerably larger service area, the capital cost and the risk of incurring substantial maintenance costs with these more sophisticated pumps and wells is a considerable deterrent to group ownership. Government ownership and**



**responsibility for major maintenance, combined with group responsibility for operation and all running costs, appears to be a practical compromise.**

### **Large capacity public tubewells**

**The term, as used here, includes wells owned and operated by government agency, or owned and maintained by such agency but operated by cultivator groups. They are referred to as "direct irrigation" wells, the water being applied directly to land in the vicinity of the well. In a second category of public wells the outflow discharges into a canal which also carries surface water, the combined flow then being distributed through the surface system. The latter are referred to as "augmentation" wells. They are discussed later, under the heading of conjunctive use.**

**Much of the above discussion of medium-capacity wells also applies to large-capacity wells. There are, however, two additional factors to be considered in the operation of a large well. The number of cultivators in the well group is much greater and the output of the well is sufficiently large that it requires division, two or more cultivators irrigating at the same time. Such wells commonly have capacity in the range of 30 to 100 liters/sec (approximately 1 to 3 ft<sup>3</sup>/sec). They are also relatively deep, usually 100 to 200 m.**

### **Technical problems in design and construction of medium and large tubewells**

**The remainder of this discussion is devoted to selected design and operational features of medium and large tubewell installations in smallholder areas.**

**Particular attention is paid to commonly recurring problems. The stages of major**

**well construction are drilling, installation of casing, screen, and granular filter if any, well development and testing, and finally pump installation. There is an extensive literature on the theory and practice of tubewell construction (Driscoll, 1986).**

**The key to tubewell performance is the design of the screen and filter system in relation to the character of the surrounding aquifer. Where the latter is relatively coarse-grained (sandy gravel) no separate filter may be needed. In the process of well development, the fine material is washed out of the formation in the immediate vicinity of the well screen, and a stable radially-graded natural filter is formed. The well is then referred to as "self-screening".**

**The situation is more complex where the aquifer is of finer material such as coarse to fine sands, commonly inter-leaved with silts. Even with the minimum practical width of screen opening (about one millimeter) an excessive amount of material would be washed out in the course of pumping, with subsequent collapse of the formation in the vicinity of the screen. Under these circumstances, a granular filter ("gravel-pack") needs to be placed between the screen and the formation (commonly 5 to 10 cm in radial thickness). The choice of the gradation or grain size of the granular filter is a function of the width of the screen slots and the gradation of the aquifer formation.**

**The problem encountered with such a filter pack installation is in washing out the drilling mud from the filter and the adjacent formation. The use of drilling mud, a mixture of bentonite clay and silt-sized cuttings, is essential to the direct rotary drilling process. This dense fluid supports the wall of the hole being drilled and also removes cuttings. It is continuously circulated during drilling, being pumped**

**down through the hollow drill-stem and rising through the annular space between the stem and the wall of the well Part of the mud seeps into the formation, sealing it against excessive mud loss. On completion of drilling, the mud remains in place, supporting the well, while the granular filter is poured into the annular space between well-screen and wall. The mud is then displaced from the well by water, and the process of washing the residue of mud from the filter and adjacent formation is undertaken.**

**This is not an easy task if the filter and the formation are fine-grained. Various techniques of surging, over-pumping, water-jetting, use of compressed air to create turbulence, and addition of detergents, have been worked out. Faced with the same problem the oil-well industry has pioneered the use of big-degradable material in mud formulation. The mud breaks down to a low-viscosity fluid after a period of time, and is more readily washed out than bentonite mud. However, such materials are sensitive to temperature and other factors and are not generally suited to tubewell construction in the region under discussion. Water-jetting involves the use of small high-pressure nozzles positioned inside the screen and discharging out through the screenslots into the filter and hopefully into the formation, producing intensely turbulent washing action. Used in conjunction with "wire-wound" screens with continuous spiral openings, this can be effective. However, the jet can lose most of its velocity in passing through the filter, before it encounters the formation. Cleaning the mud from the filter and formation and associated "well development" (washing out a proportion of the fines in the formation) can be a difficult and time consuming procedure, requiring long experience in this field.**

**Another drilling method which may be employed for holes of 18 inches or greater,**

**is referred to as "reverse rotary., where the drilling fluid flows in the opposite direction, i.e. down the annular space and up the drill rod, instead of being pumped down the hollow drill rod and flowing up the annular space between rod and well, as in "direct rotary. drilling. Generally, reverse rotary drilling does not require the addition of bentonite to the drilling fluid, making the subsequent washing of the granular filter and adjacent formation simpler than with direct rotary. However, the use of the direct rotary method is restricted by the type of formation, depth to watertable (must be less than ten feet), amount of make-up water available, and other factors. Further, the minimum hole size is greater than desired for most irrigation applications. Currently, direct rotary drilling is the most commonly employed method for medium and large capacity irrigation wells in alluvial formations.**

**Key factors remain, including the design of the screen (wire-wound stainless steel appears to be the most effective and most durable solution), the grain size or gradation of the filter and the method of placement, and the method of washing out drilling mud and well development. The result of using excessive size of screen openings and grain size of filter, in relation to the formation, can be excessive "sand pumping" and early well failure. If sand pumping does not stabilize at a satisfactorily low level after well development, the only course is to reduce the rate of pumping (and the exit velocity from the formation) until the rate of production of sand falls to an acceptable level. The penalty for inadequate washing of drilling mud from the filter and the adjacent formation is low well yield and high pumping head (i.e low specific yield), reflecting in pumping energy required and reduced size of service areas.**

**The above discussion underlines the needs for care in the investigation, design,**

**and construction of medium and large tubewells, particularly in areas of difficult formation characteristics. A well designed and constructed tubewell installation can have a life of fifteen to twenty years or more. With less appropriate design or less satisfactory construction, safe yield may be substantially reduced, and the life of the well may be relatively short.**

### **Water distribution from medium tubewells**

**With tubewells of the capacity under discussion (up to 30 liters/sec) the size of service area is likely to be in the range from 15 to 30 ha, depending upon well capacity and design irrigation intensity. In a smallholder environment, with fractionated holdings, the number of individual parcels to be served may be as much as 100. Distribution of water in this situation raises a number of questions, both technical and operational.**

**Subject to availability of power, supply at the well-head is available virtually on demand, making the cultivation of a wide variety of crops including high value specialty crops possible, provided that a similar degree of reliability can be provided at the field boundary. The situation calls for an efficient distribution system, with close farm delivery.**

**Buried-pipe distribution is the desirable solution, particularly as sufficient head can be provided at the well to permit use of pipe of relatively modest size. The closed-loop type of system makes further economy in pipe size and cost possible. With the appropriate layout, the closed-loop type of system permits outlets for every 2 or 3 ha. At additional cost of pipe and outlet valves, outlets can be provided at every hectare if necessary. From the valved outlet to the field,**

**conveyance is by short earthen channel. Technically, this is a very sophisticated system compared with supply from a canal via unlined tertiaries serving 30 or 40 ha. The question remains how to make the best operational use of it.**

**The ideal situation would be for any outlet to be able to take water at any time, in the same manner as from a household tap, and the pump would respond accordingly.**

**However, there are technical and operational limitations. The well (in the case considered) supplies at a fixed discharge of 30 liters/sec rate. This rate is, in fact, a desirable size of stream for efficient conveyance in unlined channel from the valved outlet to the field, where it may be further divided between plots or furrows. Therefore, the first operational restriction is that one outlet at a time should be in use, and one farmer at a time should use that supply (possibly two, by mutual arrangement). This ensures adequate stream size for efficient distribution, and also permits recording the amount of water used by the farmer, as it is simply the product of the well output and the time of irrigation. Opening many valves simultaneously should be avoided, except in the special circumstance of the whole area being under paddy, when a small flow from each valve may be desirable.**

**Operating with one outlet valve open at a time involves scheduling both supply to each of the fifteen valves, and irrigation by the several individual farmers served by each valve. The various procedures adopted in such operation are aimed at simplifying the scheduling process. One arrangement which has considerable merit is to divide the service area of the well into seven units each of 4 or 5 ha (six units if the well is to be shut down for one day each week), each unit being**

**irrigated on one fixed day of the week. Only the outlets serving a particular unit are in operation (one at a time) on that particular day, and only the farmers within that unit are concerned in scheduling operations on that particular day.**

**As scheduling becomes simpler the smaller the number of cultivators involved, a variation which could be considered where holdings (specifically parcels) are very small is to divide the well command into 14 rather than 7 units, the day being divided operationally between morning and afternoon. Each unit would then be 2 to 3 ha, certainly small enough to be self-managing as far as internal scheduling is concerned.**

**While conceptually it would be simplest for each unit to have its own outlet valve, technically this is not essential. A particular outlet may serve different units on different days, although this involves having a branch of a distribution channel traverse the unit in which the outlet is located, enroute to a neighboring unit. This situation could invite misuse, and may be partly responsible for some of the problems which have been encountered in distribution from tubewells. Operationally one outlet valve per unit would be preferable.**

**The above discussion refers to a medium well delivering 30 liters/second to 30 hectares, one outlet taking the whole of the well delivery at a time. A larger capacity well, for instance delivering 60 liters/sec, poses an additional operational problem, as the well discharge is too great to be handled effectively by an individual cultivator. Furthermore, distributing that flow through a single system would require large pipe size. In effect, the delivery system has to be divided, into two sub-systems each of 30 liters/sec and each seeing 30 ha. Arrangements within each subsystem with respect to division into fixed day of the week units are**

**the same as discussed for the 30 liters/sec medium well. However, means have to be provided for dividing the output of the well into two equal parts. This cannot be done simply by bifurcating the delivery line from the well into two branches, with each seeing a 30 ha sub-system, as the frictional resistance to flow in the two branches may not be equal. It depends upon the respective distances from the well of the outlets in operation at the time. This problem can be overcome by the use of an elevated tank with two identical outflow weirs each discharging into a stand-pipe supplying one of the sub-systems. Division of flow is then made at the well, and is independent of the location (or number) of the outlets upon in the two sub-systems. There is, however, an additional problem. With the 30 liters/sec well provision had to be made for shutting off the well (automatically or manually) when the outlet taking water was closed. In the case of the 60 liters/sec well with two sub-systems it may occur that one only of the subsystem ceases to take water, the other one continuing. This requires not simply shutting off the well, but reducing its output by half. In the case of a diesel-driven pump this can readily be done by reducing the engine and pump speed. However, a conventional A C. electric motor operates virtually at one speed only. If the output of an electrically-driven pump is to be capable of being halved, there are two design options. One is to provide a control valve on the pump outlet line, the valve being partially closed when reduced flow is desired. The other is to cycle the pump at full flow on/off into a balancing reservoir, withdrawing from it at the desired constant reduced rate.**

**Partially closing the outlet valve is the course taken in a manually-controlled installation, when spill at the riser results from one of the two sub-systems ceasing to take water. Partial valve closure can also be automated, by float control from an elevated tank (an arrangement common in municipal supply systems).**



**Disadvantages include energy loss inherent in operating against the additional head imposed by the partially closed valve, and increased wear on the pump thrust bearing due to the additional head. Neither factor is a serious consequence if operation with only one sub-system taking water occurs for a small proportion of time (ten to twenty percent).**

**The use of a balancing reservoir and cycling the pump on/off avoids the energy loss of partial valve closure. However, the viability of this system depends upon the provision of adequate capacity in the reservoir, and hence the frequency with which the pump must be switched on and off. Limits to this frequency are imposed by motor heating (five to ten minutes between starts, depending upon the type of motor), wear on the pump thrust bearing at the moment of start-up, wear on switchgear, and the effect of associated surging on the stability of the aquifer formation. Again, none of these factors are critical if operation of one sub-system, rather than two, occurs for only a small proportion of time. The proviso is adequate pondage capacity in the regulating tank.**

**The tank may be elevated, discharging directly into the buried-pipe distribution systems (requiring a head of four or five meters), or it may be at ground-level, requiring a second stage of lift into the two distribution systems. The elevated tank is in some respects the simplest solution, and has been widely used. It may also be employed in conjunction with a float operated pump outlet control valve, the combination of control valve and regulating tank reducing the size of elevated tank required and the degree of closure of the control valve. However, the surface tank or small earthen reservoir, with second stage of lift, provides the ultimate in flexibility as the pondage capacity can be relatively large and the cycle time with one sub-system only taking water can be an hour or more. In effect, it completely**

**separates the operation of the well from the operation of the two distribution sub-systems, and the subsystems from each other. The total pumping head and energy requirements are not affected by dividing the lift into two stages. The second lift is by simple centrifugal pumps (about 5 h.p. each). Each sub-system may be independently automated, with float control on the riser, as previously described for the 30 liters/sec well.**

### **Functions of the tubewell operator**

**A perennial question with medium and large tubewells is the role of the tubewell operator. In some cases, he is in complete control of the well and distribution system He operates the well and the outlet valves, organizes or approves all delivery schedules, and determines water charges for each cultivator. He also performs routine maintenance on equipment and maintains records. The operator or his helper must be present whenever the well is running, and conversely operation ceases if they are absent. The annual salary of the operator and helper in some government-owned and operated systems equals the annual cost of power for the well.**

**A question of particular interest is what the duties and responsibilities of the tubewell operator should be in the context of cultivator ownership and operation or at least of cultivator operation of a well. As the cultivators would collectively be meeting the cost of the operator, they would presumably wish to minimize that cost by transferring some of the duties to the water user group itself, or by eliminating certain functions through automation of the system. A key item in the latter category is control of the tubewell pump. The irrigation distribution systems under discussion are low-pressure pipe and incorporate an open riser adjacent to**

**the well to limit the pressure to the pipe in the event that all outlet valves are closed and the pump is still running. With such a provision, when the operating outlet valve is closed, spill occurs at the riser and continues until the pump is shut off. This requires the presence of an operator. However, if the riser is substituted by an elevated tank with float control, the pump can be automatically shut off and restarted when an outlet valve is again opened. Various protective devices can also be provided in the switchgear to automatically safeguard the pump against power supply deficiencies. Presence of a full time operator is then no longer needed at the well. Moreover, cultivators irrigating possibly half a kilometer away from the well can open or close their outlet or change operation to a different outlet. As far as the equipment is concerned, inspection several times per day is all that is required. The operator would also record the hours of water use by the individual cultivators in the particular unit receiving water each day and check the totals against the reading of an hours-of-running meter at the well. The task of billing cultivators for water, dealing with overdue accounts, and making payments for power could be either by the operator or by a designated member of the water user group for the well.**

**Diesel-driven installations can also be equipped for automatic starting and stopping in response to opening or closing of an outlet valve, through provision of an elevated float chamber. However, more frequent inspection during the course of the day is required than in the case of electrically-driven units. If an operator is required to be continuously in attendance, in any case the automatic, start-stop provision can be dispensed with in favor of manual.**

## **Power supply problems**

**A principal problem with operation of publicly-owned and operated large well systems in some areas has been deficiencies in electric power supply. The deficiencies have included limited hours of availability, unpredictable outages, and low voltage. With unscheduled power outages rotational irrigation schedules break down and unauthorized operation of outlet valves becomes prevalent. Attempts to ensure reliable power supply by constructing "dedicated" feeder liners, nominally reserved for supply to public tubewells, have not been as effective as hoped for.**

**There are obviously limits to the extent of power supply deficiencies beyond which it would be impractical to pursue further installation of electrically-driven public tubewells. However, there are means by which the consequences of power shortages can be minimized. First, the size of service area of a well should be designed with reasonable conservative regard to the hours of power supply likely to be available. Second, in anticipation of the occurrence of unplanned power outages, the scheduling of irrigation to cultivators should be kept as simple as possible, with entirely independent operation of sub-systems (if the well supplies more than one delivery system), and the delivery units kept as small as possible. The procedure scheduling irrigations lost by individual cultivators through power outages should be clearly understood by all concerned.**

### **Comparison of medium and large wells**

**The above discussion has referred to medium wells with capacity up to some 30 liters/sec, supplying a single distribution system, and large wells of greater capacity supplying two or more distribution sub-systems. Choice between the two depends on economic and operational factors. With regard to the well and pump,**

**there are economies of scale, the larger capacity well having lesser fixed cost per unit of output, particularly where a relatively deep well is necessary to reach the aquifer. With regard to the distribution system, the opposite is the case. Cost of water distribution systems (whether canal or buried pipe) increase per unit of area served with increasing size of the area supplied. In the case of tubewell systems with distribution of the type described there is a significant upward step in distribution cost when multiple (two or more) subsystems are introduced, as with large wells, rather than the single system of the medium well. This is due to the need to provide for one of the sub-systems ceasing to take water while irrigation continues in the others. The means of doing so have already been discussed (outlet control valve, elevated regulating tank, or surface pondage with supplementary lift).**

**A further significant cost item is the pumping head required. For a particular well, dynamic drawdown increases with rate of pumping. Where the depth to static watertable is great, differences in dynamic draw-down may not be very significant as a proportion of total pumping head, although still important in absolute terms. For a lesser depth to watertable, dynamic draw-down can be a very important item, largely determining pumping energy requirements and favoring the use of a smaller capacity well.**

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- ➔ □ **Chapter 15 - Conjunctive use of surface and groundwater**
- 📄 **Definitions**
- 📄 **Direct conjunctive use**
- 📄 **Indirect conjunctive use**

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**Chapter 15 - Conjunctive use of surface and groundwater**

### **Definitions**

**In the narrower sense, conjunctive use refers to pumping from tubewells directly into a surface water canal system, supplementing the surface supply. In a broader sense, it refers to any use of groundwater within an area also supplied with surface water.**

**The term conjunctive use does not necessarily imply that the groundwater utilized originates from seepage from the surface supply in the area concerned, although it may often do so. The sources of the groundwater may be outside of that area some distance away. In the case where the source is recharge from the surface supply, the reason for groundwater development may partly be to control rising watertable or simply to utilize the recharge which would otherwise move outside**

**the area as sub-surface flow and be lost to that area (although eventually appearing elsewhere as an increment to stream-How).**

**In general, where a source of groundwater recharge exists in an area supplied by surface water canals, technically there are two options for its use. One is to pump groundwater directly into the canal system (direct conjunctive use), and the other is to develop tubewell irrigation within the nominally canal-irrigated command (indirect conjunctive use). In the second case, the tubewell irrigation areas may be islands of purely tubewell irrigation within the nominal canal command, particularly in tailend areas which otherwise would depend on poor canal supply. Alternatively, the groundwater development may be in the form of private wells scattered throughout the canal command, supplementing canal supply in the low-How season or providing more frequent irrigation of specialty crops than is available from the rotational canal system (O'Mara 1980).**

### **Direct conjunctive use**

**A key question in the design of direct conjunctive systems is the category of canal into which the groundwater should be discharged, primary, secondary, or tertiary. If the system is rotational at the secondary/tertiary level, there is an incentive to pump into the primary canal, permitting continuous use of the pumps. Alternatively, pondage capacity may be provided in the secondaries or tertiaries, or in small lateral storage, permitting pumping to be continued during the "off" period of the rotation. Pumping into secondaries (generally selected secondaries) has an advantage if the secondary/tertiary system is lined, as higher delivery efficiency may be obtained than if delivery is into an unlined primary canal. However, the proportion of groundwater to surface water is likely to be**

**considerably higher with discharge into selected secondaries than with discharge into a primary canal. If power supply is unreliable, the operational consequences of interruption to pumping (the reduction in canal flow) are more serious in the case of discharge into secondaries than into primary canals.**

**Poor quality groundwater, requiring blending with canal supply, may be a reason for adoption of direct conjunctive use, also for delivery into the primary canal rather than selected secondaries due to the greater dilution in the primary. However, where indirect use is in the form of small tubewells scattered throughout the canal command, leaching with canal supply during the high-flow season may permit irrigation directly from wells, even with poor quality water, during the remainder of the year.**

**An advantage of direct conjunctive use is the greater degree of control on of groundwater extraction exercised by the irrigation agency as opposed to indirect conjunctive use by small privately owned wells. This may be of considerable importance where regulation of watertable is an important factor. Cultivators may or may not wish to install wells in an area where canal water is available for most of the time, at much lower cost. If wells are in fact installed, they are likely to be run only during periods of restricted canal supply, without regard to the need for consumptive extraction for watertable control They are even less likely to install wells if canal irrigation has already raised the watertable sufficiently to partially water-log much of the area, thereby reducing its productive capacity and the ability of the cultivator to recover the cost of the well.**

**On the other hand, direct conjunctive use implies a continuing budgetary demand on the irrigation agency for the cost of power, particularly if relatively large**



**capacity wells are employed, with substantial draw-down and pumping head. It is noted that attempts to interest cultivator groups in taking over augmentation wells discharging into the tertiary canals, at no capital cost to the group, have not always been successful. The group then has to meet all energy charges. Technical problems in sharing the water pumped into a communal channel are also a deterrent.**

### **Indirect conjunctive use**

**As discussed above, the development of groundwater by small tubewells or dugwells within a canal irrigation command can be a very effective means of conjunctively using the recharge from canal irrigation. The use of such wells for dry-season irrigation of perennials such as citrus and bananas can permit closing canals at a time when canal delivery would be small in any case and inefficient. A degree of control on such development can be exercised by provision of credit, and particularly by electrification and favorable electrical tariffs, but otherwise the rate of installation of such wells is determined by market forces.**

**A further means of indirect conjunctive development, previously noted, is the installation of medium or major wells and their distribution systems in selected areas within the gross boundaries of a canal command, but separated from the canal system as far as supply is concerned. ("Islands" of purely groundwater impaction within the canal command). If utilization of recharge from the canal irrigation and watertable control are the purposes of the conjunctive installation, draw-down of the watertable below the critical level for small suction-mode wells by the installation of medium or major wells is unlikely to be a problem. Small privately owned wells and larger group-operated medium or major wells may then**



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  **Chapter 16 - Pumped lift irrigation distribution**

 **Background**

 **The application of individually owned small pumping units**

 **Centralized pumped-lift systems**

## **Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)**

### **Chapter 16 - Pumped lift irrigation distribution**

#### **Background**

**Major diversions from a river generally involve construction of a weir, raising the water level high enough to enter a canal system supplying the command area. Such a diversion has the merit of operating entirely by gravity. However, the cost of the weir can be considerable. If the amount of flow to be diverted is small in relation to the flow in the river, and particularly if the river channel is deeply**

**incised, it may be more practical to dispense with the weir and to pump from the river up to bank level, from which point distribution is by open canal system or, in some cases, by pipe.**

**Pumped lift installations range in size from major pumping stations supplying thousands of hectares down to small portable pumps owned by individual cultivators and serving one or two hectares only. The limitation of the small privately-owned units is that they can reach only a narrow strip of land paralleling the river and about a kilometer in width. If it is desired to serve an area several kilometers in width there are two options. One is to excavate small supply canals, at river-level, into the area to be irrigated. Small pumps then draw from these canals. The other is to install government-owned centralized pumping units at intervals along the riverbank and to distribute by gravity canals or pipeline, into the service area. Cultivators do not use pumps, but take water from the canal or pipe system by gravity. Both types of system are discussed below.**

**The application of individually owned small pumping units**

**The practicability of constructing river-level supply canals to serve small pump units depends largely on the depth of cut required. If the river is deeply incised, this course would be impractical. Where the river is tidal, however, the supply canals can be designed to fill during the high portion of the tidal range, being closed by tidal gates during the low portion of the range and functioning as storage until again filled on the next tide.**

**The small pumps, generally diesel or kerosine operated, may be owned by the cultivator or may be leased from a central agency. It is noted that one of the**

**largest pumped-lift operations, using small group-owned units, is supplied not by a river but by major canals. This is the system used since historic times in the Nile delta, where the major canals have water level below ground level, and water is lifted 1 or 2 m by animal-driven water wheel, or manually, from small lowlevel supply canals. A current issue is the advantage of filling in the supply canals (a saving in cultivable land) and substituting central pumping units on the main and branch canal banks, with buried pipe distribution.**

**Unauthorized low-lift pumping from major canals is widely practiced by cultivators in some areas in South Asia, to the extent that it may well be questioned whether this should not be considered a legitimate component of distribution in canal systems. It would permit irrigation of a strip of land on one or both sides of a principal canal, an area which is usually difficult to serve directly by the gravity canal system. There would, of course, be a problem with control of the amount of water pumped, particularly as the primary canals from which such pumps would usually operate run continuously, not rotationally.**

**The same problem is encountered with direct gravity outlets on such canals, illustrating the fact that technically desirable, logical, features in a distribution system may be ruled out on management grounds if solution cannot be found to the problem of control**

### **Centralized pumped-lift systems**

**A centralized pumped-lift intake on a major river can pose a number of technical problems including changes in the course of the river, siltation of the intake during high-flows, and the wide range in river-level between high and low-flow seasons.**

**The magnitude of the monsoonal flood-flows of the major South Asian rivers, often in highly erosible channels, makes river control extremely difficult. Protection of the site of a pumping station against erosion may be feasible, but little can be done to prevent the low-season channel on which the pumping station depends from changing its position during a flood, to reappear half a kilometer away from the station when the flood recedes. Location of the station on a stable reach of the river is of course desirable, but such a site may not exist in the vicinity of the area which it is intended to irrigate. Work may be necessary in the river-bed at the end of each flood season, to re-establish a lowflow channel at the intake. However, it must be acknowledged that considerations of channel instability can rule out the installation of fixed pumping stations in some situations, making smaller moveable units the only feasible solution.**

**Some of the rivers in question carry extremely high silt loads during the flood season. Pumping is stopped at such times, partly to prevent carrying silt into the distribution system and partly because there is little demand for irrigation at that time. However, the intake can remain exposed to siltation. If the intake has a conventionally-shaped convergent approach structure, a low velocity eddy is likely to form in the intake area (the pumps being shut down), with heavy deposition of silt in the intake and the pump chamber. The solution to this major problem in one installation was to provide closure of the intake structure Bush with the river-channel, providing no opportunity for eddy formation.**

**The very wide range in river-level between low-flow and high-Dow seasons has caused much ingenuity to be exercised in the design of pumping stations for lift irrigation. One system widely used has the pumps and motors mounted on a moored floating pontoon. This requires the use of a telescopic or other adjustable-**

**length pipe arrangement connecting the floating pump station to the fixed outlet at the top of the bank, a system which requires considerable attention during periods of varying river-flow. Another alternative utilizes a propeller pump at the lower end of a fixed inclined pipe extending up the bank. The propeller is driven by a shaft extending up the inside of the delivery pipe and connected to a motor at its upper end. At considerably greater structural cost, a pump chamber may be provided at low river-level, with vertical drive-shaft extending up to a motor on a platform above maximum flood level.**

**Water distribution from a major pumped-lift installation is generally by canal system, and the earlier discussion of such systems is relevant. However, pumped-lift diversions offer the possibility of sufficient head to permit the use of buried-pipe distribution, particularly in smaller and medium capacity installations. Distribution can then be basically similar to that previously described for medium and large capacity tubewells, the river-lift pump substituting for the tubewell pump. Differences are simply of scale, river-lift installations ranging up to a greater capacity than commonly encountered with tubewells. The river-lift pumping station is also located on one boundary of the service area, while the tubewell is more often located within that area.**

**One type of layout used for pumped-lift distribution systems has delivery lines arranged in radial fashion, extending from the pump station towards the perimeter of the service area. Outlet valves are located at intervals along each line. A deficiency in this arrangement is the fact that the area served by an outlet valve is much greater near the outer perimeter than near the hub of the radial system (the pump station). The distance to be run by earthen channel from the outlet to the individual plot is also greater and reliability of supply is consequently less.**

**Furthermore, if several outlets are open together on one of the lines, the hydraulic head on the outlets near the pump and their discharge are substantially greater than further along the line. Consequently, the area near the pump is usually more intensively irrigated than the remainder, the net result being an undesirably small effective service area.**

**Several efforts have been made to install flow regulating devices on outlet valves, to ensure equality of discharge regardless of head. While this should be technically feasible, there has been little success in designing a tamper-proof system. In fact, a robust low-cost, low head flow control valve (20 to 30 liters/sec, head ranging from 1 to 5 m) is much needed, but has not yet been developed by irrigation equipment manufacturers.**

**As previously noted, an adaptation of the system used for medium and large tubewells may be employed as an alternative to the radial (or branching) layout. This divides the pump command into sub-areas each of about 30 ha, and each with a pipe loop system and outlet valves. Supply to each sub-area is controlled by an elevated float chamber, the demand within the sub-area being signalled back hydraulically, to a central chamber at the pump house which regulates the amount being pumped. Such regulation is facilitated in the case of pumped-lift installations, compared with tubewells, as the pumping capacity can be divided between several pumps. Output is adjusted by running the appropriate number of pumps. The system described offers the possibility of largely self-management by the cultivators within each sub-area.**

**A final factor in pumped-lift installation is largely riparian. Many such installations are pumping from the braided channel systems of deltaic areas. Further**

**consumptive extraction can cause the saline/freshwater tidal interface to move upstream, adversely affecting existing pumping installations lower in the delta. Mathematical modelling of the often intricate tidal flow pattern within the deltaic channel system may be necessary in such a situation to determine the feasibility of further pumped-lift installations and their location.**

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 **(introduction...)**

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## Foreword

**Irrigation is the largest public investment in many countries in the developing world and is a primary area of international assistance. With total World Bank lending of 29 billion in 1991 US dollars, the World Bank has played an important role in financing irrigation investments in the world. The Asia region has been the chief recipient of World Bank lending for irrigation, receiving 70 percent. India, with 27 percent of irrigation borrowing, is easily the largest client. Today, the domestic demand for agricultural products is largely met. This success could not**

**have been achieved without the last half-century's investment in irrigation.**

**As one of the principal inputs to food production in South Asia, irrigated agriculture continues to play a critical role in achieving food security and poverty alleviation and improving the quality of life. However, the constraints posed by land and water scarcity, population growth, increased demand for water for human and industrial use and rising incomes, and the associated need to raise the carrying capacity of the land in a sustainable manner require efficient and flexible irrigation and drainage systems.**

**While irrigation development in the region over the last 30 years can claim a considerable degree of success, it has not been without problems, some of which are yet to be solved satisfactorily. The problems do not generally relate to the basic hydrology or hydraulics of irrigation, but most frequently to the poor management of the water resources in the unique smallholder environment of the South Asian region.**

**This paper presents and discusses the issues that characterize smallholder irrigation in South Asia. Land development for irrigation, the design and management of water distribution, selection of crops, and the pattern of water use at the farm level must all be viewed in the context of the end user, the small largely independent cultivator. The degree to which the individual cultivator can reasonably be expected to forgo some of his independence in the interests of efficient use of a communal source of water becomes a central issue in the effective design and operation of smallholder irrigation in South Asia.**

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**Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)**

**Chapter 17 - Technical and operational improvements in rehabilitation of irrigation projects**

**Introduction**

**The merits of rehabilitation of existing irrigation systems versus construction of new projects have been debated for the last two decades. International financing**

**agencies have increasingly favored rehabilitation. This is not an opinion which has always been shared by developing countries. In an earlier conference of the International commission on Irrigation and Drainage (ICID), there was a strong plea that priority be given to new construction, as "cultivators served by an existing project already have some supply of water, however deficient, while those in areas as yet unirrigated have none.. The view was also expressed that rehabilitation was a slow and difficult task, and less likely to have a major impact on agricultural production than new projects. It was also not considered a vehicle for substantial aid inflows.**

**The increased recent emphasis on rehabilitation and improvement has been due to a number of factors, including the diminishing number of sites available for new projects and the greater recognition of ecological constraints on new work, particularly on reservoir construction. Projections of future demand for agricultural production can now no longer be matched by projections of area to come under irrigation from new projects. Increased productivity from existing irrigated areas is essential and that implies extensive rehabilitation.**

**Judged by crop production per unit of water used, there is certainly room for improvement in most South Asian schemes, and it is commonly asked to what extent could this situation be improved by adoption of the new technologies in water distribution and irrigation being practiced elsewhere. While there is indeed opportunity for injection of new technology, this would unfortunately address only part of the problem. The causes of the low productivity are to some extent inherent in the variable nature of the monsoonal climate and the limited possibilities for regulation by storage. The consequent uncertainty of irrigation supply has given rise to a number of social and management problems which do**

**not have easy solutions.**

**One approach has been to attack the management problem first, making better use of the existing irrigation infrastructure. Notable increases in production have been achieved in some situations through such an approach and at low cost. However, a study of water management problems usually also discloses deficiencies in infrastructure either at the lower end of the system (the tertiary level) or further upstream. These must be remedied before improvements in management can be effective. Current World Bank practice (e.g the National Water Management Project in India) is to carry out a thorough review of the performance of a project including effectiveness of water use (selection of crops to be irrigated, seasonal use of stored water, etc), evaluate infrastructure and operational procedures, and analyze cultivator attitudes and problems before embarking upon any improvement program. Solutions developed are very much project-specific. However, there are a number of areas which can be discussed in general terms.**

**The dam and reservoir**

**Net storage capacity, rate of siltation, and dam safety are of interest. Storage capacity is of premium value in a monsoonal climate. The net capacity available at a particular site is influenced by the amount which must be reserved for flood rise, above normal retention level, during passage of a flood. This is determined by the magnitude of the design flood and the nature of the spillway, particularly its crest length and whether or not it is gated. Public safety is involved, as over-topping of an earth-fill dam can be disastrous. Safety against over-topping runs counter to the interests of irrigation as far as allocating storage against flood rise is concerned. With increased attention to safety (particularly by international**

**agencies), review of a dam in conjunction with a project rehabilitation study frequently leads to an increase in estimated design floods and increased flood rise provision, diminishing the net storage capacity available for irrigation purposes. Modification of the spillway to increase its effective length, in some cases by installation of simple automatic or tilting gates, or possibly raising the crest of the dam may be desirable. The addition of protection to the downstream slope of embankment dams to control erosion in the event of overtopping is a new development being widely practiced elsewhere, which could be relevant to this question. Dam safety also includes the subject of dam stability and a project review could result in reduction of normal storage level unless remedial works are undertaken.**

**The geography of the reservoir site and of the associated canal service area usually limits the level to which the reservoir may be drawn down by gravity flow through the main canal. Below that level is dead storage. Some of the latter (at the upstream end of the reservoir) may function as silt storage, but for the most part it remains unutilized. Where there is normally more than sufficient seasonal inflow to fill the live storage and spill occurs, there may be a case for utilizing part of the dead storage either by releasing the water through low-level outlets in the dam and rediverting at some point downstream, or by pumped-lift from the reservoir into the main canal. The latter arrangement, while not normally incorporated in original construction, could well be attractive as part of an up-grading program, particularly where the shape of the reservoir basin makes the volume of otherwise dead storage very large.**

**Siltation has grossly reduced the storage capacity of many small reservoirs in much shorter time than anticipated. Reduction in rate of siltation is a difficult**

**problem, but as discussed earlier, catchment erosion is often largely focused on particular locations and project rehabilitation could well include attention to such areas.**

**Summarizing, any rehabilitation study for a project which incorporates a reservoir should include re-examination of dam safety, including flood discharge capacity and dam stability. The possibility of increasing net storage capacity by spillway modification or other means should also be considered. Reduction of sedimentation rate by selective treatment of the catchment may also be feasible, and could be relevant to future performance of the project.**

### **The canal system**

**Canals are frequently in dire need of maintenance, including silt removal and clearing of vegetation, and canal linings may be in various stages of deterioration. However, improvement works may need to go beyond simply reinstating the original canal condition. Two factors should be reviewed before any such work is undertaken. These are the desirable canal capacity and the method of operation of the canal system.**

**Developments in cropping within the command since the design of the project, or now contemplated, may indicate the need for greater canal capacity in the peak season than originally provided. This can be accommodated during canal rehabilitation by a change in the canal section or in some situations by lining.**

**The desirable method of operation of the system is the key question in project rehabilitation or improvement. It is not a simple question to address. The basic**

**alternative methods of operation of an irrigation system, either regulated or run-of-river, have been reviewed in Chapter 8, in the context of a new project. The situation in a rehabilitation project is complicated by the existing canal system and the present status of water distribution. It is not possible, or desirable, to wipe the slate clean and to begin afresh with a new system. Adaptation and compromise are likely to be necessary.**

**New hydraulic structures may be required on primary and secondary canals, their nature depending upon the choice of operational system aimed at and the nature of the existing structures. In the case of the tertiary canal system, a change in basic layout may also be required. This can present problems as the tertiary comes close to the cultivator. A principal deficiency in many older irrigation systems is the undesirably large area served by a tertiary (or watercourse), and the considerable distance between turn-outs from the tertiary to the typical farm boundary, without the benefit of formal field channels. Supply to the outer perimeter of the tertiary command is then poor, and water use tends to be focussed on the more fortunate headend cultivators.**

**The design of tertiary distribution systems has been discussed in Chapter 7. The question in project rehabilitation or improvement is to what extent the existing tertiary system should be modified or up-graded to bring it more in line with the current design approach. Such modification could include reduction in size of the tertiary command by construction of additional tertiary channels or leaving the tertiary system virtually unchanged but constructing additional quaternary (field channels) with control structures at branches from the tertiary. The choice of modification, if any, may depend on the degree of self-management expected to be exercised by the water user group and the views of the cultivators.**



**Where there is good cooperation within the group and a desire for self-management, modification of the existing tertiary system may be minimal, consisting largely of removing particular deficiencies pointed out by the cultivators such as more favorable location of certain tertiary intakes, addition of control structures, provision of additional crossings over tertiaries, and lining of selected reaches with particularly troublesome seepage. A more comprehensive tertiary lining program may be justified in some situations. On the other hand, where cultivators have shown little capacity or inclination for group management within the tertiary command, modification to decrease the command size (by construction of additional tertiaries), and to avoid the need for operation of structures within the command, may be desirable.**

**As noted earlier, any tertiary modification program aimed at improving equity or efficiency of water distribution is likely to reduce the supply to those cultivators who are using excess water at the headend of the system. If an attempt is made to recover the cost of the work directly from the cultivators, resistance to payment is to be expected.**

## **Drainage**

**Generally in an irrigation project, poor drainage is evident as high watertable, as areas of sustained inundation after heavy precipitation, and as very wet conditions in low-lying areas throughout the monsoon season. Problems of maintenance of primary and secondary drainage have been discussed in Chapter 11, and also cultivator attitude to tertiary drainage.**

**As far as drainage is concerned, many irrigation projects have been designed**

**largely on the philosophy of wait and see, with minimal initial construction. However, the necessary follow-up action, where drainage indeed proves to be a problem, is not generally taken. Inadequate drainage can make cultivation impossible in the wet season and, incidentally, can also make living conditions within the village intolerable. Consequently, construction of additional primary or secondary drainage may be a priority item in project improvement. It may also be strongly urged by the cultivators.**

**Rehabilitation of a drainage system is unfortunately not a one-time operation. Desilting and clearing need to be repeated at intervals. As emphasized in Chapter 11, an essential feature of a drainage improvement program should consequently be the provision of permanent access for equipment beside each major drain, to facilitate future maintenance. The other essential item is the provision of permanent crossings over the drainage channels, to avoid obstruction through partial in-filling by cultivators constructing informal access-ways.**

### **Introduction of high technology irrigation methods**

**As discussed in Chapter 3, the most commonly practiced form of water-application by smallholders utilizes the level basin. The basin is of course essential to the cultivation of paddy, also where paddy occurs in mixed cropping. It is also frequently the preferred arrangement for purely non-paddy crops, with or without furrows within the basin.**

**With well prepared basins and reasonably timely water application, the irrigation efficiency obtainable within the basin is relatively good. Inefficiencies are more likely to be within the conveyance and distribution system. However, with water**

**undoubtedly being the limiting factor in future agricultural production, the question of the possible role of much more efficient, more sophisticated, irrigation systems in South Asian agriculture is of interest. The systems referred to include sprinkler, drip, and micro-sprayer. Low-pressure buried-pipe distribution to outlets supplying hand-held or roll-out plastic hose serving individual orchard trees, quick-coupled portable pipe systems operating in the same manner, and portable gated pipe are in similar category.**

**Such systems are in fact already in use in South Asia, and are being actively promoted by equipment and pipe suppliers. So far, however, their application has been largely confined to production of specialty crops by individual large cultivators. The water supply is usually from tubewells, which can provide the near continuous service necessary for economic utilization of such systems. Further expansion of their use is likely to be in the same direction, rather than using canal supply which is commonly rotational at the farm level. Where tubewell supply is not available small pondages periodically filled from canals can provide supply to the systems discussed. This is being practiced for highvalue specialty crops in some area. However, the use of such systems for field crops is unlikely in the foreseeable future. Lining of tertiaries, possibly in conjunction with the use of roll-out portable plastic sheet linings for quaternaries (field channels) is more probably the next step in improvement in efficiency of water use for field crops.**



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#### Chapter 18 - Ecological and riparian factors in irrigation development

##### Introduction

The anticipated ecological impact of a proposed irrigation project is now a primary factor in the evaluation by international development agencies. In World Bank practice, an Environmental Assessment report is in fact a prerequisite to further examination of a project. A number of ecological issues which should receive attention are discussed in the following notes, including riparian factors, which have determined the fate of a number of prospective projects. Relevant Operational Directives and Guidelines issued by international agencies should be referred to for further detail.

##### Ecological issues in groundwater development

**An important issue is the effect of a proposed development on existing groundwater use in the area, particularly on the watertable regime and the operation of existing small wells and dugwells, including those providing village water supply. Provision of alternative supply may become necessary. The substitution of good quality water from deeper project wells in place of contaminated water from shallow open village wells can be a positive factor. Quality of groundwater and its long-term effects on soils in the irrigated area can be an important ecological consideration, particularly where water quality is marginal.**

### **Surface water development**

**The introduction of canal irrigation usually leads to a change to two-seasonal or three-seasonal irrigated cropping, which can have an important effect on the incidence of water-related diseases in the project area. Exclusion of irrigation from the immediate vicinity of villages may be necessary.**

**As discussed earlier, canal irrigation can cause a rise in watertable and increased surface runoff, both of which can cause a deterioration in drainage conditions unless adequate drainage measures are designed into the project. Some of the historic ecological disasters resulting from irrigation have been due to the rise in watertable bringing saline groundwater near the surface. Soil salinization over extensive areas has resulted and large scale tube drainage installation has subsequently been necessary to remedy this situation. Where there is risk of such occurrence in a new irrigation area, the subject should be addressed and control measures specified.**

**Ecological problems arising from reservoir construction have been much in the public eye in recent years. The prospective reservoir basin is frequently an inhabited, cultivated, area. The increased agricultural production resulting from irrigation of downstream areas, using the stored water, will usually exceed the existing current production within the basin by a factor of several times. However, the benefit to the downstream cultivators comes at the cost of those within the reservoir basin, who are displaced by the project. Token cash compensation to the reservoir "oustees" is no longer considered an acceptable solution. They must be re-located elsewhere, in an area offering means of livelihood.**

**However, in a country in which all available land is already occupied, or under forests, finding a suitable area for re-location can be difficult. Relocation into the downstream irrigation area can be a partial solution where there are a sufficient number of large holdings which can be subdivided under land reform provisions. It is not, however, a generally applicable solution. Furthermore "oustees" may resist being relocated to an area distant from their original home. Establishing new settlement areas by clearing of forest lands, preferably near to the reservoir area, is a possible solution technically, but may run counter to national policies regarding preservation of forests. One trade-off can be afforestation of an equal area of marginal lands elsewhere, at project cost. However, resettlement of reservoir oustees remains a problems. Preservation of endangered species of wild-life and flora within the reservoir basin may also be a factor.**

**Where a reservoir is, in fact, included in the project plan, and where the reservoir basin includes areas under forest, the question of clearing of vegetation before initial filling must be considered. Trees left standing, and submerged, can inhibit the use of the reservoir for fish culture, particularly the use of nets, apart from**

**being most unsightly. The decomposition of smaller vegetation under submerged conditions can, in some situations, generate highly toxic outflow unusable for irrigation for a period of several years.**

**Where irrigation headworks including dams, intakes, and the upper reaches of the supply canal are in hilly terrain, erosion resulting from canal and road construction on steep unstable slopes can also be a major ecological factor in project evaluation.**

### **Riparian issues**

**Any new consumptive diversion from a river reduces downstream flows and may adversely affect existing or prospective downstream users. Conversely a proposed project may be adversely affected by future upstream diversions or storage. Such circumstances may be the cause of serious disputes. They may occur between neighboring projects within the same state, or between states, or across international boundaries. There is no universally-accepted legal framework for settling such disputes, particularly at the international level. Development agencies consequently endeavor to avoid becoming involved in such problems by requiring, in principle, that riparian issues be addressed, and agreement between the riparian parties be reached, before a project is accepted for appraisal. However, there may be little incentive for the riparian parties, other than the one desiring the new development, to reach such an agreement. A downstream riparian can almost always find some disadvantage, and withhold consent on that account. Thus, the prospective financing agency, while seeking to avoid involvement, may nevertheless have to inject some judgement as to the relative merits of a case, to avoid needed development being held up indefinitely on**

**insignificant grounds. In exercising that judgement, the agency can provide a forum for airing the positions of the parties concerned and for technical fact-finding.**

**Not only consumptive diversions but also flood protection works can be the subject of riparian dispute. For instance, embankment construction to prevent a river from flooding across adjacent agricultural lands reduces the flood storage in that reach of the river and correspondingly increases the downstream flood-flow. Where the river crosses an international boundary between the upper and lower areas, a riparian dispute may result, requiring evaluation of respective upstream and downstream effects.**

**An international financing agency can have an important role in riparian disputes concerning major international rivers by funding the works required to provide a mutually acceptable solution. Division of the waters of the Indus River following partition of India, involving extensive works funded by the World Bank, is a notable example. However, decades of negotiation and the prospect of major Bank financing have failed to result in a solution elsewhere.**

**Turning to very much smaller works, riparian issues may be encountered in the improvement of village-constructed diversions from a small stream. There are frequently a number of diversions down the length of the stream, each having its own primitive brush-wood weir. The weirs frequently fail, passing on the flow to downstream diversions. An informal system of priorities of water rights has been established by tradition, based largely on the nature of the weirs. Any effort to improve the most upstream weir to provide more security to the diversions at that point reduces diversions at downstream weirs, upsetting the traditional balance of**



**water use. It may be necessary, in these circumstances, to supply the downstream areas by canal, from the upstream improved diversion weir. However, the formal division of the water between upper and lower areas, taking the place of the traditional informal division, may involve protracted village-level negotiation.**

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 **Design and Operation of Smallholder Irrigation in South Asia (WB, 1995, 134 p.)**

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-   **References**
-  **Distributors of world bank publications**

## References

## Notes:

**Enquiries regarding procurement of World Bank publications listed below should be addressed to The World Bank, Box 7247-8619, Philadelphia PA 19170-8619, USA**

**For copies of IIMI publications, enquiries should be addressed to the International Irrigation Management Institute, 107 Havelock Road, Colombo 5, Sri Lanka.**

**Berkoff, D.J.W. (1990). Irrigation Management in the Indo-Gangetic Plain, World Bank Technical Paper No. 129, Washington, D.C.**

**(1987). Matching Water Requirements in Large Systems with a Variable Supply. Experiences in India, Reprinted in ODI/IIMI, 87/3d.**

**Byrnes, KJ. (1992). Water User Associations in World Bank-Assisted Irrigation Projects in Pakistan, World Bank Technical Paper No. 173, Washington, D.C.**

**Doorenbos, J., and W.O. Pruitt (1977). Guidelines for Predicting Crop Water Requirements, FAO Irrigation and Drainage Paper No. 24, Rome.**

**Driscoll, F.G., ed (1986). Groundwater and Wells, 2nd edition, Johnson Filtration System, Publisher.**

**Frederick, K.D. (1993). Balancing Water Demands with Supplies. The Role of Management in a World of Increasing Scarcity, World Bank Technical Paper No. 189, Washington, D.C.**

**Hillel, D. (1987). Efficient Use of Water in Irrigation. Principles and Practice for Improving Irrigation in Arid and Semi-arid Regions, World Bank Technical Paper, No. 64, Washington, D.C.**

**Hoffman, G.J., T.A. Howell, and K.H. Solomon, eds. (1990). Management of Farm Irrigation Systems, American Society of Agricultural Engineers Monograph.**

**Jensen, M.E., R.D. Burman, and R.G. Allen (1990). Evaporation and Irrigation Water Requirements, American Society of Civil Engineers Manual No. 70.**

**Le Moigne, G., S. Barghouti, H. Plusquellec, eds. (1988). Technological and Institutional Innovation in Irrigation, World Bank Technical Paper No. 94, Washington, D.C.**

**Malhotra, R.C., ed. (1987). Monitoring and Evaluation of Irrigation Projects, International Fund for Agricultural Development Regional Workshop.**

**Martin, E.D., R. Yoder, eds. (1987). Public Intervention in Farmer-Managed Irrigation Systems, IIMI, Sri Lanka.**

**O'Mara, G.T., ed. (1980). The Conjunctive Use of Surface and Groundwater Resources. World Bank Symposium.**

**Plusquellec, H., and T. Wickham (1987). Irrigation Design and Management. Experiences in Thailand and its General Applicability, World Bank Technical Paper No. 40, Washington, D.C.**

**Plusquellec, H. (1988). Improving the Operation of Canal Irrigation Systems. An Audiovisual Production, World Bank, Washington, D.C.**

**Richards, L.A., ed. (1954). Diagnosis and Improvement of Saline and Alkali Soils, US Department of Agriculture Handbook No. 60.**

**Shah, T. (1989). Efficiency and Equity Impacts of Groundwater Markets: A Review of Issues, Evidence, Policies, World Bank Colloquium on How to Reach the Poor through Groundwater Irrigation, April 1989.**

**Sundar, A. (1990). Promoting Peoples' Participation in the Rehabilitation of Tanks**

**in Karnataka, Reprinted by ODI.**

**Sundar, A. (1990). Managing Public Irrigation Systems. Reprinted ODI.**

**Tanji, K.K, ed. (1990). Agricultural Salinity Assessment and Management, American Society of Civil Engineers Manual No. 71.**

**Toulmin, C., and M. Tiffin (19987). Groundwater Management, Equity, Feasibility and Efficiency. ODI/IIMI paper 97/1e.**

