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EFFECT OF WATER CHARGES ON IRRIGATION SYSTEM EFFICIENCY

by

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* See LeBaron (1984) for an earlier working paper on this topic

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SUMMARY

Water charges are not only a source of revenue, they may act as prices and affect short-run resource allocation. What might we expect such charges to do and under what circumstances? In this paper we lay out our thinking on these questions.

Might water charges be manipulated in such a fashion as to lead to "efficient" resource use? We look at more than one meaning of efficiency but except for special well known situations, the answer is no or probably not. In an illustrative example we show that on traditional surface systems it may be profitable for farmers to be "inefficient."

If this is true, the best way to think of water charges is as a source of revenue, and not be too concerned with allocative impacts. The most pertinent implication of this argument is that the simplest and cheapest arrrangements for collection may be good enough. There are many ways to collect irrigation system related revenue that do not involve water deliveries at all. Irrigation systems will have to achieve certain types of efficiency through adaptive improvements in day-to-day operation; charging polices might play a limited role in reaching this goal.

The critical factors for predicting impact of charging systems upon effective water use are the flexibility or responsiveness of a system to water requirements of individual farmers and the protential method of fee collection. a) a Very responsive system would be equivalent to a single pump that can be cycled when crops need water. Very few surface systems can even begin to be operated this way. b) It is difficult to optimize more than one goal with a single instrument. Moverover, only a limited number of collection methods are viable. As a consequence, water charges cannot be expected to lead to significant improvements in application "efficiency" as usually defined. c) Low field irrigation efficiencies found in traditional furrow methods are almost insensitive to water charges.

Many of these conclusion are not at variance with what has been written by others (Small, Adriano & Martin). In those cases where there does seem to be a difference, an explanation might be found in a different reference frame: the basic allocation problem is not represented by the available irrigation water but rather by the resources tied up in the conveyance facilities. In greater

or lessor degree these facilities are not responsive to charging schemes that tend to affect all irrigatiors as a group. The rat of resource use is controlled by means other than price.

Paddy rice cultivation is outside the focus of this paper and the manay difficulties surrounding better system management are not treated in detail. Selecting the level of water charges is not a theme, although references are made to "ability ot pay" and "marginal benefits."

METHOD AND SEQUENCE OF ANALYSIS

The many difficult issues involved in poor project management are not a primary focus of this paper, although they are not wholly ignored. The underlying assumption is that if water charges are levied, they are paid. Other simplifying assumptions are made in order to move through a number of arguments, a few at a time. The main topics to be considered are listed in Diagram 1. This diagram is a stylized outline of a spectrum of factors that might influence our thinking about programs of irrigation water charges.

"Mechanism" refers to the specifics of how charges are imposed and collected. "Measurement" refers to irrigation water. "Financial efficiency" as shown in Digram 1 is a catch all phrase employed as an umbrella for all notions of about pricing use of public resources at social cost. Application and conveyance efficiencies are defined wholly in agronomic/hydraulic terms. A few interactions are indicated.

The method is to refer to some range of possible physical situations, or administrative procedures, and ask the question, "how would farmers react under these combinations of circumstances?" In this way we define the important limits and ranges of real world expectations, even if it is impossible to consider every combination of water price policy/farmer response.

Revenue goals may be separated from efficiency goals. The tax incidence of collecting revenues may be discussed without differentiating between public and private systems, ignoring as well, details of confusion, maldistribution and legal contraventions. This simplification concentrates our attention on how farmers might react to new or increased cash requirements imposed by the the government or through group membership, leaving to one side questions of "efficiency." Once "efficiency" issues are the focal point, particularly in public systems it will be unnecessary to dwell on farmer responses in detail.

In a similar manner, by referring to a range of water source situations, it is possible to move on to ask ourselves just what

would be required system-wise, and supply-wise, before MC pricing could play a role in achieving conveyance operation at a "socially" optimum level, given sunk costs?

The next major section explores what is implied by application efficiency relative to a range of common system types and situations. What does efficient water use mean? If fees are imposed or altered, will efficiency be improved? How will the users as a group react? Will taxpayers obtain more production?

In the last section water prices or taxes are ignored altogether. How will a farmer react to the supply received relative to the quantity necessary for most efficient production? What if he receives exactly the right ratio, could the farmer in traditional furrow systems use it in the most "efficient" way? Data from India give some support to the argument that low percentages for on-farm irrigation efficiency are hard to alter. Investment at the farm level is required, but the long-run variable costs and returns may not be attractive enough to call it forth.

Diagram 1. Some interrelationships of water charges topics

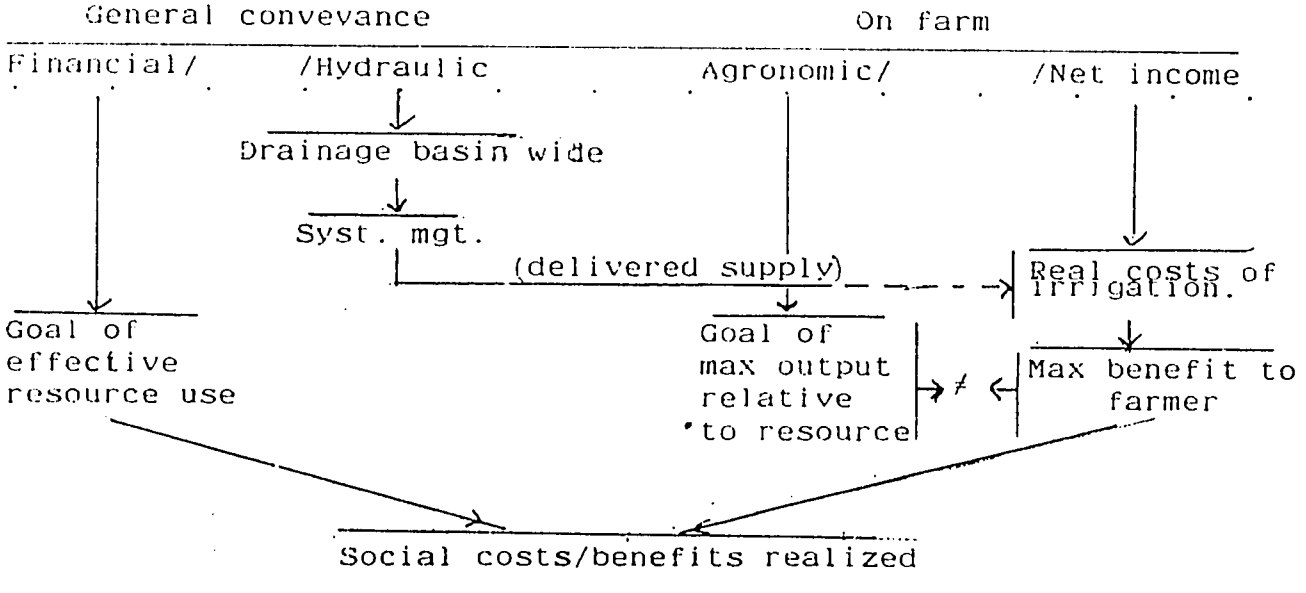
REVENUE GOALS

General	O&M	Cost / Investment
User rights in pv't. systems & idea of controlling resource.	Specific in private systems-- pay own way.	
	Possibly specific in public systems Involves subsidy and incidence of any water user charge.	

Any fee levied on farmers by government or private groups acts as a tax.

Private Systems	Public Systems
Ability to pay.	
Assume they know what they are doing.	Potential difficulties: irrigation is expensive.
Collection Mechanisms.	
Its their problem (unless they squabble)	Can get expensive. Relation among compliance, ear-marking, farmer participation and Agency performance. Need for multiple incentives.
Timing & Basis of Charges.	
Of little public interest.	What situations provide oppertunity for tax to act as short-run price, rather than fixed cost? Roles of flexibility and measurement.

EFFICIENCY GOALS



PUBLIC FINANCIAL GOALS

The only reasons for fee collections by the State are to a) obtain general or adminstrative revenues; b) recover O&M or investment costs of facilities; c) ration use of public resources, or regulate use of a water source that has been privately appropriated to ensure that benefits are widespread. In the context of this paper, the "efficiency" aims (c) are a separate topic; some of these aims can be satisfied without fees. The average farmer does not distinguish between these goals, to him a tax is a tax.

The State can levy any tax or charge it chooses, to recover construction costs, O&M costs (or both), or simply to obtain general revenue or possibly to obtain some direct affect on the level of resource use. The State has the power to utilize any collected revenue as it sees fit. Just because a water charge is collected for O&M does not mean that the revenue will really be dedicated to that purpose. Collections to secure general revenue, say from users on private systems, might be handed over to a nation's hydraulic agnecy or be treated as an offset to that agency's general and administrative budget. However, collections made relative to retiring a construction loan probably will be applied to reduce debt.

In this paper O&M and investment recovery charges refer to collections in respect to a particular public system. General revenue refers to any collections from water users for non specific purposes.

The level of water charges required to carry out selected purposes, may be quite removed from any mechanisms available for fee collection. In turn, the range of operable collection mechanisms is governed by the physical characteristics of the system in question. Generally not a lot of choice is open.

From an individual farmer's viewpoint, whether the system is private or public has virtually no effect on how he reacts to a tax. Moreover, insofar as cash is involved, the individual farmer does not distinguish between fees for O&M and fees for investment cost recovery. He merely hopes that the collections will support smooth operation and good maintenance; he may or may not have influence in bringing this result about.

General Revenue

It is almost impossible to conceive of general revenue in connection with public systems unless the collections more than cover the State's O&M and annualized investment cost accounts. Even if there is no formal book keeping, the net effect is to balance tax income against outlays and, until equal, there can be no increment to general revenues. If the farmers get rich in a public system, they can contribute to general revenues in a number of ways. It is possible to think of general revenues in connection with private systems. In such systems, recurrent and investment cost recovery are not objects of the State's fiscal activities, neverthless, private water appropriators might well be taxed.

In Ecuador, for example, all the 200 plus private water user groups pay an annual tax related to the esimated flow (lt/s) of their source or diversion. The flow rates are rechecked from time to time and collection levels adjusted. The rates are low, the compliance is high and the revenues are an important budget component of the National Institute of Hydraulic Resources (INERHI). The tax is justified in the nation's water law on the basis that some reimbursement of the general public should be made by private users of an important resource. In Ecuador the fees probably bear little relation to any kind of social costs that might be involved in issuing, managing, or adjudicating the water rights in a given situation, although the law also specifies that effective water use is a public goal. No effort is made to reach the goal indirectly by a tax; to the degree it is achieved, it is through direct regulation of the source.

O&M Revenue in Public Systems

There is a natural tendency for irrigation system managers to accept responsibility for a greater share of system operation whilst passing some portion of maintenance chores onto the farmers served. In this way the pressure to collect fees is reduced and, if the users do a good job, the level of required supervison may be quite tolerable.

It might be the responsibility of individual farmers or groups to keep earthen ditches and canals free of weeds and provide

labor for other tasks that are defined by the system managers from time to time. The types and amounts of O&M that can be carried out by the users and their animals is mainly a function of the sophistication of the system. There is not much for users to do if conveyance channels are all lined, or individual fields are served by buried pipe. At these extremes, any non-subsidized O&M levys will have to be paid in cash.

It is conceivable that the amount farmers must pay might vary from year to year, depending upon programmed repairs scheduled in various sub-systems or districts. Dominican Republic farmers in the Yaque del Norte irrigation district have some say in what work they think needs to be done, and in how their share of any extra costs will be met. In this same district the managers have an incentive to ensure compliance in fee payments because most of the collections remain at the district level to be used for O&M purposes. It is conceivable that water users might also obtain a voice in setting the size of the cadre of public employees who handle day-to-day system operation. This may sound utopian but it is obvious that if there is any trend towards greater operational control of irrigation systems by the water users, the trend would lose a lot of its meaning unless there is matching growth in water user control over the operating budget.

Farmers will adjust to any requirements for cash outlays for on-going operating costs in a manner no different than in adjusting to any other tax. What they do will depend upon the timing, the collection method and flexibility of the irrigation system. It is difficult to believe that any "lumpy" manintenance expenditures would have much effect on short run production decisions, although a given farmer might expect benefits to his long run supply of water. Some sort of average cost fee calculation and simple collection method that might allow for special assessments will no doubt suffice.

Construction Cost Recovery

If farmers are to repay a share of the construction costs, we would expect to see a range of resource allocative adjustments no different in response to any other tax levied in a particular manner

Such decisions are not the focus of this section, however. The important issue in investment recovery revolves around the overall cost share that farmers are assigned.

One point of view is that farmers should not bear any construction costs. This position is not explored in this paper. We only note that proponents are bound to explain where the benefits to society are. If their explanation involves improving farmer incomes, then the farmers may as well pay something. If the benefits do not involve income improvement, then why give farmers a productive tool to play games with?

Selecting the amounts that must be repaid involves questions related to what a system is expected to accomplish, i.e., how the expenditure of public resources can be justified. Project purposes are not wholly production oriented. The decision to provide water to create farmsteads in the American Desert was motivated by non-economic criteria. Dams are built to serve multiple purposes. Nowadays we speak of integrated rural development projects.

It is a useful shorthand to refer to some projects as being "welfare" oriented, to distinguish them from "production" oriented projects. However this simple categorization has to include a grey area of "consumptive" purposes that provide a lot of utility that water users are very willing to pay for: all the way from green lawns to potable water supplies. So all welfare elements are not necessarily subsidized, while those that are involve obvious provision of social services such as bath houses and medical aid stations or other equity related elements. It would be unusual to require farmers to bear all the costs of such elements, even if they are the group who gets most of the benefit.

The usual procedure is to relate investment recovery to a project's productive elements, in this case, to the irrigation features. But this is not always feasible. These features, by themselves, tend to be expensive and require production of valuable crops as an offset. It is common to encounter facilities that cost so much that it is hard to imagine any reasonable cropping pattern that might amortize them. Farmers should not be asked to pay for realizing the dreams of engineers and politicians. One rule might be that farmers' "low side" ability to pay would be calculated in terms of producing ordinary crops. Project promoters would then have to justify the public subsidy of residual costs as best they may.

One of the most often employed arguments to justify subsidy in an irrigtaion project is that there are secondary economic benefits that go beyond farmers' ability to pay. This means that there are worthwhile productive benefits that the general public may obtain. Presumably these benefits are multiples of value added by farmers.

So it comes down to whether the farmers really will produce enough to create the fundamental benefit stream. The only thing certain is that taxpayers may not see all the hoped for output.

This suggests another rule of thumb that would limit public subsidy of productive elements to an annualized sum that would be more or less proportional to the ratio of secondary to total economic benefits. Another way of putting this is that the taxpayer would only pick up subsidy related to some value over and above what would be expected from primary beneficiaries in terms of value added in any case. Otherwise, why make the committment?

If repayment requirements are not built into farmer beneficiaries' cost curves, they will not have an incentive to get beyond their own "break even" output levels, and move towards the value added levels expected of the project. The idea that irrigation farmers will all work hard and extract all the rents inherent in a project design and situation, is not borne out by experience. Their main cash flow goal is to cover their auto consumption and other production costs and to hold onto their land. Striving for any output value beyond that is problamatic.

Fees, Taxes and Cost Curves

It is natural to think that imposing water charges for whatever purpose may affect rate of use of resources in the short run. This is because any fee acts as a tax, and the reaction to a tax may be to reduce output (input). When collected or how collected defines whether or not the tax shifts farmers' variable costs or annual fixed costs. The textbook way to effect day-to-day production decisions would be to levy some sort of excise on each unit of a product sold or, upon each unit of a variable factor utilized in production. A fee to acquire a permit to do business, purchase a franchise, etc.. is an overhead that may increase the short-run fixed costs of doing business, but will have no affect upon the rate of production.

In practice it is unlikely that irrigation charges could get into short run variable cost curves (requires that there be a volumetric measuring system in place and possibly that the water releases can be controlled). At the same time is incorrect to imagine that "fixed costs" might not have impacts upon seasonal water utilization--there is always some moment in time when they are also variable. For example, payments made at the start of the cropping season are going to have a different impact on water use than if made after the season has passed.

Impact of Method and Timing of Water Charges Collections

It is common for farmers to attempt to purchase or trade water when their crops are dry. They may try to bribe the ditch rider to give them some extra water or they may steal from their neighbors or complain about someone else who is taking water out of turn. These tactics do not constitute a charging mechanism, no matter how beneficial they may be as an intra-seasonal water resource allocators. A typical charging system requires the farmers to pay a flat amount per season depending upon the quantity of land owned or operated. If farmers have learned from experience that they do not get equal treatment from the engineers, they resist paying.

What follows is not meant to describe any actual situation because water fees would not and problably could not be collected as imagined in these thought experiments. Every water user is assumed to pay an assigned share of the global cost. How does the form and timing of the levies affect the activities of the average farmer and the amount of water entering the project? In the real world the irrigaton authority may act as the tax collector, but that does not mean that the authority does not want to deliver water--or ever reduce use by very much due to the charges.

Start of Season

If the levy is made at the start of the irrigation season, and water can be supplied to farmers on a flexible basis, the amount of revenue collected will be a function of the general price elasti city of demand for water by the group before land preparation begins. Water demanded from any source will be cut back by such charges, possibly by agreeing to shortened turns or through some other adjust ment. It is not unusual to have to make some sort of declaration about up-coming water needs, before planting gets underway (based on proposed cropping patterns for example). Thus it is possible to obtain an allocative adustment from individual farmers or from the user group through a tax that will be treated as a short-run fixed cost.

Once such an agreement or decision has been made, an individual farmer will be happy to receive as many actual units of water during the growing season as possible since payment has already been made. Indeed, farmers have to live with what they get, but they would be unhappy to not take delivery of the minimum paid for.

These speculations serve a purpose because we are forced to realize that some questions would need to be answered about alternative uses for the "unsold" water if taxes were imposed or increased and the farmers reacted by cutting back average water demand.

During season

In Peru water users make declarations <u>and pay</u> in advance of the season. Or, they can pay by the month <u>in advance</u> during the season.(Sarria, 1986)

If the levy is somehow collected during the course of the growing season, as units of water are delivered, there may be some general reduction in use if farmers run short of cash or there is a lot of rain, or whatever. The irrigation Authority might raise prices to cut consumption or lower them if marginal costs warrent the action. We might imagine that these individual "purchase" decisions would cancel each other (if the farmers who were willing

to pay for more water could obtain it), thereby ensuring that the net water flow into the system would be unaffected. But why would such decisions cancel? There might be a tendency for the majority of users to make the same kind of allocative decision at the same moment. Again, whether there is an alternative use for any "unsold" water, "outside" the current user group could be an issue.

There are run-of-the-river situations where for some reason less than possible diversion is occuring. It would be technically possible for farmers to purchase "at will" within the irrigation season if diversions were increased. If some purchasers do not come forward, the water wastes or is used by some other group down stream. This discription suggests a scene where average irrigation demand from within the project is low and it is conceivable that LOWERING a water charge would induce farmers to take more water. But, since individuals cannot store much, it is unlikely that they will pay any amount if they do not need it. So this is too contrived to be very useful. It would be more usual for system managers to push through all they can divert.

In short, even the most casual analysis leads to the conclusion that if intra-seasonal charges are expected to affect overall project use rates there needs to be a mechanism to utilize any "water savings" that could possibly be supplied to additional farmers, plus recognition of a requirement that water deliveries be capable of being switched on and off or shifted here and there at will. Probably a minimum requirement to achieve this amount of flexibility would be for a system to at least have provision for storage. In addition, a secondary requirement probably would be existance of some sort of local "water market" that would "clear" the supplies that some farmers were unwilling to buy in a particular part of the season. These requirements are seldom satisfied although some systems in California, or Spain, France, and Morocco come to mind.

End of Season

Suppose the tax is collected at the end of the irrigation season, what then? This timing of collections conforms with experience, but not much really changes. In unusual situations, as noted, an individual farmer might be able to request water when he needs it during the season and, no doubt, some sort of real or esti-

mated volumetric delivery record would be kept so that he could be billed accordingly at harvest time.

As hinted above, it is possible that the amount to be collected or the rate of charge would be known in advance of the moment of collection, probably before the cropping season begins. Therefore, farmers might make some water use adjustments in contemplation of what the final charges are likely to be. By the time harvest is in, a farmer will have received whatever was delivered (or that he was able to get his hands on). If no record has been kept and there has been no pre-seasonal declaration (that he was held to), the farmer is controlled strictly by how the system is operated and how well it has been designed. He knows he wll pay some fee based upon some average unit of reference.

Summary

Fees to recover construction and O&M costs of irrigation facilities can be levied in any number of ways that have no connection with water deliveries, or in amounts that have no connection with the cost of providing water. An easy way to link irrigation water with fees is via the land area served. This is fine if actual water deliveries satisfy general crop needs or are stable and proportional.

If an irrigation system is capable of responding to intra-seasonal variations in individual farmer demands, or certain farmers can obtain more than their alloted share, a means of tracking actual volumes delivered is desirable. Many tube wells and specialized surface irrigation systems satisfy this requirement. Individual farmers or even entire systems might use "excess" water, but at least they would pay for it.

It is possible to imagine ways to collect fees that might affect levels of farmer use in other situations. Declaratons about the amounts desired during a season could be followed up through adjustments in ditch rider routines. It is also conceivable (but improbable) that irrigation water levies could cut down the amount of water entering a project. If fees are collected at the end of the irrigtion season and have not been influenced by farmers' desires, then what happens during the season depends entirely upon how the systems are operated.

A lot of utility may be obtained from normal system measuring

devices even if individual farmer deliveries cannot be tracked. A real benefit of measuring canal flows is to help ensure that the seasonal quantity of water available to the system is divided up among the commanded land units according to system design, i.e., according to sizes of the various land parcels to be served. Once even this level of equity is achieved, collecting according to irrigation water units or land area amounts to about the same thing.

Orderly Systems

Thus, the actual measurement units in which water charges are based or collected have little if any seasonal effect on farmers served by systems that run more or less as designed. If the fees are raised, all farmers are affected on the same relative basis. Furthermore, there is no need to reduce average water use by fee increasss in a system running as designed because if "extra" water is availble from the source in a given season, and there is a use for it elsewhere, the excess does not need to be turned into the system. If there is a shortage of water, the managers will push through all that they can. Only if there were enough flexibility in the entire delivery system to accomodate intra-seasonal requests for water, would volumetric measurement make a difference to farmers' decisions. Otherwise, they simply do the best they can with whatever is delivered.

Disorderly Systems

Apparently the important thing is whether the system being considered operates in an orderly fashion. As is well known, many do not. (There are various manifestations of disorder which, in this paper, are lumped together as "head/end-tail/end problem systems.) Probably a large share of literature dealing with irrigation water pricing overlays an image of HE/TE problem systems. Therefore we have to ask, "What twist does a HE/TE situation put into the conclusions reached so far?"

The basic contention runs about like this: It is probably a good idea to have a system of water charges, and if it is based on a volumetric

rather than area measure, then farmers who take or use the most water per land unit will pay above average and might cut back. On the other hand, given existing head-end/tail-end relative utilization levels, collections on an area basis do not get the job done from either an efficiency or equity standpoint.

This sounds reasonable at first glance because, within a project perimeter, somehow any excess over crop requirments in one location would be made available for use in another.

Apparently there is a role for use of volumetric measurement to achieve a defined type of project effeciency -- i.e., that it operate more or less as designed and solve what economists would term a distributional problem at the same time. The reasoning says nothing about whether the tail enders would be willing to pay for the newly available water, and assumes, conversly, that head enders will not buy something they do not really need. All that is sought is potential for equi-marginal production efficiency based on equi-marginal water distribution within the perimeter. (The idea, introduced above, that tax collections might reduce the average amount of water entering the perimeter in the first place does not seem to be involved.)

The way to reach distributon goals in disorderly systems is through regulation and direct action. For the price of relinquishing water charges as an instrument for achieving distributonal "efficiency", we retain some freedom for using them to pursue other goals that may be quite separate.

As a matter of fact, if an irrigation Authority has the power and the skill to collect fees, it almost certainly has the power to get order into the system and solve HE/TE problems directly through rationalized delivery patterns. Once "order" is gotten into the system, earlier concluson about collection mechanisims apply.

The number one rule for irrigation program success is to maintain order.

Volumetric Measurement and the Demand System Exception

The main elements of a demand system have already been described: physical ability of the system to respond to intra seasonal measured requests. Irrigators in a demand system are in a situation analagous to householders in cities who are supplied electricity or water for home consumption by flipping a switch or turning a tap. Two features are involved: 1) usage is monitored in some fashion: and 2) demand tends to come in peaks. Thus, capacity (storage or source flow plus delivery) must be adequate to service the peak loads--at all other times the system is under-utilized.

The classic resource utilization problem and its solution, when consumers must finance such a system, is well known. The idea is to entice end users to switch to non-peak periods. This is solved by marginal-cost pricing. In other words, tariffs are lower during off-peak periods. However, marginal-cost pricing may not recover capital costs under such circumstances. Equipment wears out, and full cost recovery may have been ineadquate for depreciation or interest on invested capital. To solve the capital recovery problem a lump-sum payment is required of users who join the system. This payment can take the form of a meter charge, a "hook-up" fee, etc.

It is easy to conceive of off peak periods within a system's operation, particularly if cropping is continuous,and farmers could irrigate at night. The periods immediately before and after the main irrigation season could be thought of in the same way. Then, in true demand systems, some useful benefits might be had by LOWERING water prices at certain times.

But it would require a very sophisticated system to make such conceptions realities. There are meters at block or UCA delivery points in some Moroccan systems, so fancy pricing procedures would be technically feasible. A big advantage to farmers is that they would not have to pay for what they do not get.

True demand systems are rare. They usually would require storage and probably pressurization as well; storage makes water demand even more "peaky" because users prefer to irrigate in daylight; the systems greatly reduce short-run variable costs so that, within limits, users need only to pay for installation in some manner and metering use can be ignored.

EFFICIENCY GOALS

In this section an attempt is made to wring out what "efficiency" means in an irrigated agriculture context.

A common idea is that farmers waste water and that irrigation charges, by putting production costs up, would lead to greater on-farm application efficiency. The general shape of a different point of view has already been made clear: simply imposing charges may or may not effect efficient water use; much depends on the type of system and the inherent range of charging collection mechanism choice. The key is good system management.

It is clear that on-farm water application efficiency is quite separate from whatever hydraulic efficiency is achieved in the conveyance facilities. Is is also clear that applicaton efficiency might be a good index of social efficiency: the higher the former the higher the latter. But a similar input/output relationship does not hold for conveyance efficiency beyond the idea that the same amount of water at the same source, will serve more farmers if the conveyance efficiency is high. This says nothing about the day-to-day utilization of the facilities, once in place.

The conclusion reached is that it is not very useful to think in convential terms about the social opportunity costs of utilizing public facilities.

The general basis of this conclusion is immediately transparent: according to the "law of sunk costs", water prices should be reduced to society's marginal cost of short run utilization of project features, whereas, charges need to be raised to reduce farmer waste!

Efficient Utilization of Conveyance Facilities

Marginal cost pricicing is the touchstone for economists' policy prescriptions involving the level of utilization of public resources. Where a large fixed investment is involved the short run social costs might be quite low. In this section the argument is made that, although sunk costs are involved in public irrigation facilities, lowering prices to MC will not affect rates of utilization in cases where

the rule can be invoked, and that in many other cases, MC pricing cannot be invoked to begin with.

For present purposes the main lines of economic thought about efficient public resource utilization can br summarized as follows: a) The best situation would be to utiiize the resource at the level where the marginal benefit (marginal value or revenue product) equals marginal social cost. This would maximize the sum o producers' and consumers' surplus. (See Diagram 2) b) If the value of the marginal product is unclear, prices might be set at the level of marginal costs associated with with whatever level of usage materializes. Thus, prices would be adjusted as costs move up or down. Either of these methods might not generate revenues that would cover all investment costs so resort might be made to a two-part tariff. c) Pricing on an average cost basis might be less efficient, but cost recovery would be automatic.

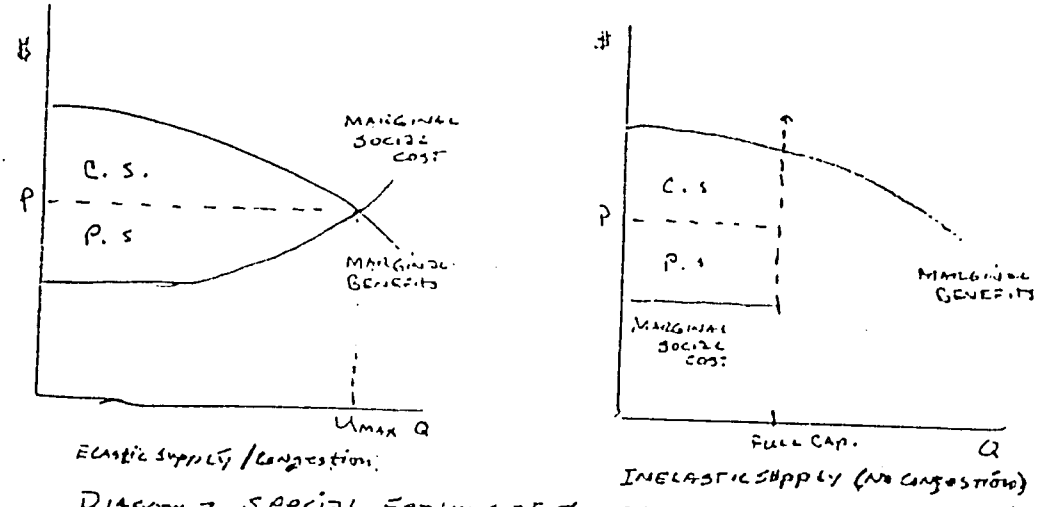


Diagram 2. Special Feature of Theory of Resource Utilization

Reference to (a) is all that we require at this point. Optimum usage requires that supply of service input(s) can expand or is adequate to equate MSB and MSC. (This equality may be "hastened" by presence of congestion on the supply side.) Ignoring any limitations on the size of the aquifer, a public tubewell system could be utilized as suggested by the left hand portion of Diagram 2. Various studies have been made of the MVP of irrigation water based on sample survey and experimental production function data. No known study also includes a discription of the "shape" of the marginal social costs of utilizing the associated public investment which underly the benefits estimates. However, there are separate studies that do make social cost estimates that might be invoked to decide whether the right hand side of the diagram is reasonably depicted.

The argument of this section is that it may not be possible to bring MSB and MSC together by means of adjusting prices because of capacity constraints of the typical irrigation system. (As drawn, the State could collect more and more revenue by raising prices and vice versa for consumer surplus impacts. To see what is going on in a high cost system or a wrong crop system, readers may wish to shift the appropriate curve up or down.)

Utilization of Investments in the Short Run

The economist's way of viewing sunk costs may cause some confusion. The first consideration is the time period before any resources are committed to the investment. During this period, risk and potential payoffs are evaluated, based upon expected selling prices of the proposed production. In the private sector, if all goes well, the investors will meet expenses, recover capital with interest, and maybe earn additional profit. They may be happy to roll their capital over into another round of investment. If they are unlucky, they lose capital or go bankrupt and are driven out of the industry. Of course, if the next investment horizon appears brighter, a new batch of capital can be rounded up and the promoters may try again.

Public sector investments may also fail if hoped for demand does not materalize or if operating costs cannot be controlled or if prices are deliberately set to confer subsidy on consumers. If costs are not covered, constant decapitalization will occur and this might be accompanied by a fall off in services offered as well.

Once the public has built facilities a certain type of reasoning applies: the schedule of charges to be levied may be set to cover full costs to society or recover just the cost share that society says must be recovered. Once a facility has been built it is possible to think in terms of sunk costs. In the private case, if planned for demand does not

materialize, the firm does the best it can to cover variable costs and recover any portion of fixed costs possible. The firm does this by accepting any unit prices above average variable cost and produces where price = marginal cost or, if it can control selling price, management cuts back output until the new marginal revenue = marginal cost. In this manner it earns as much return on the fixed factors as possible.

A public entity facing a slackening in demand cannot do quite the same thing. Although it tends to have monopoly (price setting) power, it would prefer to maintain output as though there were competition i.e. where mc=mr (or ar=mc). This choice is due to the relationship between sunk costs and society's opportunity costs. Once resources are fixed in place, the short term social costs of utilizing them are low; the more use the better. User fees need only be high enough to recover variable costs of day-to-day operation. In some extreme cases, even the variable costs are very low or nil, then the use of such fa ilities as railroad tunnel might not cost society anything once the resources are committed. Setting prices accordingly would encourage use and increase social benefits.

Where individual use decisons control "flow", the free use of the facilility may create congestion so great as to lead to total blockage. As individual costs rise due to congestion, marginal social cost rises even faster. The free or low cost use policy has to be abandoned. A special toll, equal to the difference between marginal and average social costs at peak use, may be used to reduce the waste of resources due to congestion.

The conveyance facilities of irrigation systems are somewhat like a footbridge or railroad tunnel: there is a maximum amount that can flow, given the pipe or canal dimensions and the rate. The investment in the facilities, once put into place, also represent sunk costs. But at this point the resenblance ends. Unless the faciilities are quite flexible, individual farmers cannot directly add to flow rates; they cannot cause congestion in the highway sense. There

is no gap between average and marginal social costs at capacity, there is no gap for a toll to close. Charges may be set to collect revenues and their effect might be to cause the facilities to run at less than capacity. And, if the charges are later reduced, the system might revert to full flow. Even if the costs of O&M were to be zero, and water charges were to be removed entirely, the systems could not carry additional water, even though farmers presumably would be willing to take more.

Classification of Systems by Source

Irrigation water sources such as run-of-the-river, springs, bogs, seeps and some drains, automatically put some inflexibility into irrigation systems. Intra-seasonal control and adjustment of deliveries to the command areas are limited. It is impossible to obtain more than the flow at the souce unless the flow is above average or the conveyance capacity of the facilities is generally less than the availability at the source. In these systems you take what you can get when its available. Often the source must be shared with some other right holder.

Underground and surface reservoirs/tanks afford control over deliveries until the storage runs out. The storage feature confers flexibility. Water will be released according to the system management plan, or according to some balance of need to carry over water, spill excess runoff, or generate electricity, etc. The management plan will tend to require that facilities run at design capacity during main irrigation periods. A certain amount of scheduling adjustment may be possible. Not all tanks and resorvoirs have "surplus" to sell, even if some farmers would pay for extra water.

Thus what has been termed flexibility does not really mean ability to be totally responsive to crop (farmer) needs, except under the most sophisticated systems.

The very control that is possible in flexible systems--assured or stable water releases--tends to make MC pricing inapplicable, at least in the high season, because the facilities are running full or are on strict lateral rotation, and the flows cannot be increased. In uncontrolled systems, the reverse situation applies. When there

is too much water (early in the season) the managers will be diverting all that is possible (or what farmers will use). Lowering prices will not increase flow because either the canals are full, or the farmers do not want water. During the remainder of the year, there may be excess capacity in the delivery elements, but MC pricing is irrelevant because diversions are limited by low flow at the source.

There are certain unusual situations where this argument may be modified (storage reservoirs appear excessive relative to the conveyance network). The social cost of making greater use of the storage is low, but adjusting prices or contracts downward will not encourage more throughput if the canals and ditches are running full. However, at the start or end of the irrigation season, or possibly at night, it might make sense to try to move some "excess storage" by some sort of off peak pricing. (The limitations to this procedure have been bought out earlier.)

Society obtains the most benefit from its investment in public irrigation systems if the facilities can be operated on a continuous flow basis. Marginal cost pricing may help achieve this goal in certain situations. It is nearly meaningless to advocate MC pricing as a basic charging tool.

Efficiency of Irrigation at the Farm Level

This section covers how water charges can be related to agronomic/hydraulic definitions of efficiency of use. The main conclusion is that "efficient use" takes care of itself. It all depends upon what is meant by the word.

Agronomic and Hydraulic Efficiency

In an input-output sense, neither conveyance facilities nor plants are 100% efficient. However, it is possible to speak of 100% water application efficiency if what is supplied to the plant equals transpiration. In practice this value is rarely achieved at the field level because of the expense.

There is a difference between potential plant yield and actual yield (Ya). Potential or maximum yield (Ym) is a function of available energy and can be estimated as a linear function of

Class A pan evaporation from a station inside an irrigated field. Pan evaporation is determined principally by air temperature and incident solar radiation. Actual yields are influenced by fertilization, planting density and soil moisture availability. There is a similar relationship between evapotranspiration possible (ETm) and what plants actually achieve (ETa).

Various models have been developed linking crop production to evapotranspiration. For example, the the relation of actual to potential yield can be written:

$$\left(1 - \frac{Ya}{Ym}\right) = ky\left(\frac{ETa}{ETm}\right)$$

where ky = a yield response factor that relates the decline in Ya to the unit decrease in ETa. (Hargreaves & Samani, 1984)

Therefore in order to move the ratio Ya/Ym towards unity, ETa must be moved to equal ETm.

The amount of irrigation necessary to achieve this equality is dependent on the efficiency and uniformity of water application available as precipition plus other factors. As water application is adjusted to push ETa into the range for high yields, it becomes increasingly difficult to maintain high efficiencies. (Ibid, p.345)

It is also possible to think in terms of "hydraulic efficiency." This refers to the notion that once water is brought under some human control, gravity may be employed to push it from one place to another. What winds up in the drains of one project can be used again. And what percolates into an aquifer may raise a water table somewhere else (with good or bad results) or recharge the river it was originally diverted from.

Already it has been noted that increasing project water prices to users might cause some overall reduction in water entering into the project, if the charges cannot be focused on particular users. The residual amount will be avilable for use somewhere else, or maybe it will simply flow into a lake or the ocean.

Maximum "hydraulic efficiency" means obtaining the most "duty" from a developed water resource. Thus, efficient water use may also imply something about a global view of a source and possibly a whole basin or watershed; a single project viewpoint is too narrow.

Water Charges in "Excess" and "Deficit" Situations

Private irrigation systems tend to be left alone by officials, although this may be because they can be monitored at the source or diversion, easier than at the farm level. Probably the tendency is to collect any required fees from private groups in as simple a fashion as possible, for example, in the form of annual lump assessment of some sort. In any case the collection method may or may not have important impacts upon rates or methods of water use. The group may levy its own fees in addition. This does not suggest that there might not be some adjustment of of water supply during the irrigation season. But the adjustments will come about as a group management decision and have nothing to do with levies on farmers. Group management procedures and systems of conflict resolution have to be relied upon to generate whatever the private users are willing to accept as "efficient" or "fair."

Public systems are another matter. Those based on tube wells come in many varieties. Some operate about like indidual private systems because the farmers can request water. Some deliveries are metered and the users are charged according to quantity. In others the user group may be asked to buy diesel fuel if they want the pump to run or be asked to take up a collection for spare parts when there is a break down. Thus there is a kind of self-imposed "efficient" use of water in such cases. It is the same as saying that only the amount desired will be diverted. This is not a problem because the aquifer source is a reservoir. On the other hand pumped systems often operate just like any other open channel system once the water is turned into the main canal. The pumps are run, the canal flows.

As already noted, in non-sophisticated public systems, fee collection can easily be made to cut down overall water use at the project level (cut back diversions). Presumably there would be another use for the "residual." The charges may or may not affect intra-seasonal water application rates by farmers. Also it is another matter to try to use charges to solve water distribution questions; only specialized situations lend themselves to tracking individual deliveries. This is an important problem area that might better be handled by direct action to make members of water user groups follow the rules of the project.

Excess Supplies. In discussing efficiency in the context of traditiona systems, it must be borne in mind that even a well designed gravity/furrow system will throw off water which normally will be used elswhwere, outside the project, as supplemental supply or to irrigate dry land. The only way this will not occur is if the project is designed for high technology in the first place (and no leaching is required) or if the known supply is streached to cover "too large" of a project perimeter.

Crops can only utilize so much water. If the amount available is "adequate" or "over-adequate," any excess percolates to underground aquifers or returns to the river system. Either way, eventually, other irrigators can use it. Planners should view on-farm efficiency in global drainage-basin terms; their concerns should not be limited to the specific project of interest. Water charges estimated for a project might very well be imposed on beneficiaries outside the perimeter. (We have already covered the possibility of "overuse" in one part of the perimeter relative to another.)

If more project-wide "efficient" irrigation is achieved, by whatever means, less water is diverted to fields. And, again, the residual, left in the supply network, may be used used elsewhere (immediately, relative to waiting for it to appear via aquifer movement or overland return). It is also possible that diversions are not reduced and more land is irrigated with the same amount of water (and there is reduction in potential overland return and irrigated land elsewhere).

Leaving aside the HE/TE problem systems, the most important potential use of water charges to reduce average project-wide water use, will be in situations where land is flat and water logging is a threat or is already occuring. (There might be some concurrent shifts in farmer production

decisions, especially since associted salinity problems may be present.) Whether the reduction in water application due to charges would make possible some shifts in supplies to new areas would depend on the specific water source and its basin hydrograph.

Deficit Supplies. A common situation is tht irrigation systems do not divert "excess" water, disigners and managers tend to stretch supplies and farmers feel that they need additional amounts. The users are constrained by shortage to do the best they can.

Any time water is constraining farmers are automatically forced to make an efficiency of water-use decision. New techniques will be introduced to deal with persistent shortage if cost effective methods and market incentives are available. They may realize before a season starts that water will be short. Then they have to decide whether to leave some land unplanted in order to concentrate expected water supplies on less space. Or, they may be into a growing season before some choices have to be made. They have to decide whether to short all crops, concentrate on a cash crop, save a food crop, and let the others go.

In all of these situations, in orderly systems, efficiency of water use is guaranteed by physical shortage.

Systems that are persistently short of water, however, operate under a lot of "tension." There is great temptation to steal water and disrupt whatever pattern of operation has been devised. Thus, one of the side effects of attempting to bring as many families as possible inside the perimeter to share in the benefits of better soil moisture control, is the

A system may be well designed in the sense that an attempt has been made to match the available supplies with the expected consumptive use demands of the crops, and it may still experience bad years. This is especially true for run-of-the-river and other uncontrolled systems. Vital off-season precipitation may not materialize and farmers willbe faced with water shortfalls during ensuing critical growing phases. Unless operating rules for such contingencies are enforced, tension builds as the tail-enders suffer. In the Western USA, suffering is automatic because "prior"

rights holders are supplied first in a dry year. But inside formalized, public project perimeters, designers and planners do not look forward to such institutionalized distribution effects. Probably they would prefer to spread the suffering. One of the most important aspects of keeping systems orderly, therefore, is the requirement to give even handed treatment to all users, rich and poor alike. Water user associations (or other allocating authorities) have to be both strong and fair.

In a water-short situation, existence of a system of water charges will not affect efficiency of use one way or another in an orderly system (unless they are set so high as to reduce diversions). There is no "waste" to control. If a system of charges is overlaid on top of generally inadequate irrigation supplies the goal can only be to collect revenue.

Microeconomics of Field Irrigation

It is very difficult to do a good job of applying water by traditional methods. Efficient irrigation is expensive in time, effort, and money. A rational farmer will substitute water for labor every time he has the chance and will possibly profit in the process. As Keller, et. al. have recently pointed out, "if these costs are overlooked by planners, wasting water seems uneconomic and irrational." (1986, p.1)

Probably the single biggest boost to irrigated yields is high uniformity of water application. This is what sprinkling and other high technology is mostly about (the causal observer may think that the important function of these devices is to save water, but that is secondary).

In traditional surface systems, the only way to get uniformity is to have level fields. A really high degree of uniformity requires precision levelling that is impossible to obtain by hand or animal methods. An average 2.5cm cut across a single hectare amounts to 125 m3 of earth to be moved away. This explains why rice seems to be the single crop that farmers know how to irrigate--the standing water covers up surface irregularities that even very careful paddy preparation cannot eliminate. /

A farmer has no other option than to do some minimum amount of levelling if he wants to irrigate at all. Each year he may devote the energy and money to do a little more levelling plus he always has to touch up deterioration from the year before. After that, if he aims for efficient water use, tow choices are open: he can either run up and down each furrow during his irrigation turns, hoping to "cut" the water through all the high spots before he runs out of time (or money to pay for help) or he can invest in more serious hand, bullock, or machine levelling.

No Special Levelling

Figure 1 shows the hypothetical costs at the farm level in a traditional furrow irrigation scene. A unit water supply = 1.0 is the ratio of the available water applied (AW) necessary to support actual evapotranspiration (ETa) to the amount necessary

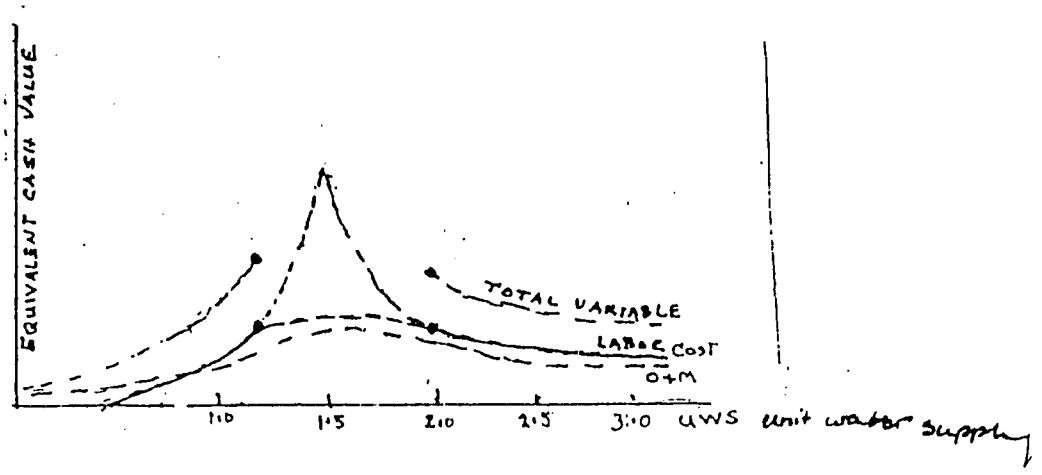


Fig. 1 Hypoththetical practical upper limits (°) on seasonal irrigation costs farmer willing to absorb and implied appiication uniformity necessary for high efficiency--no special levelling investment.

(AWmax) to support maximum evapotranspiration (ETm). Due to various inefficiencies in even the best surface systems, maximum crop yields will occur where AW/AWm = >1.0, or about 1.5. Thus the 'peak' in costs is really somewhat to the right of UWS = 1.0.

If the farmer chooses not to invest, he incurs an annual cost for irrigating his fields that is a function of how hard he tries to be efficient with the water delivered to him. The seasonal irrigation cost the farmer must bear is mainly composed of labor effort although some amount of "O&M" is involved (hoes, shovels, dam materials, calls for his help to maintain the general conveyance net work, etc.). The "dashed segment of his labor cost curve indicates that he can only "go so far" in achieving high water application efficiency in any given season. To do better would require a more or less instantaneous, infinite, investment in land levelling time and effort. By spending some additional money on tools and dams, however, he could at least manage O&M where UWS = 1.5.

O&M costs rise with the attempt to be more efficient because more tools and materials are needed by the additional laborers required. Where water management is less important, these costs fall. The shape of the labor cost curve has been partially explained. The remainder is straightforward: left of UWS 1.5, a farmer has less and less water and reasons that he can put it in any easy locations with about the same effect; moving to the right of 1.5, he has more and more water and less and less need to manage every drop. (cf. Keller, et. al., 1986)

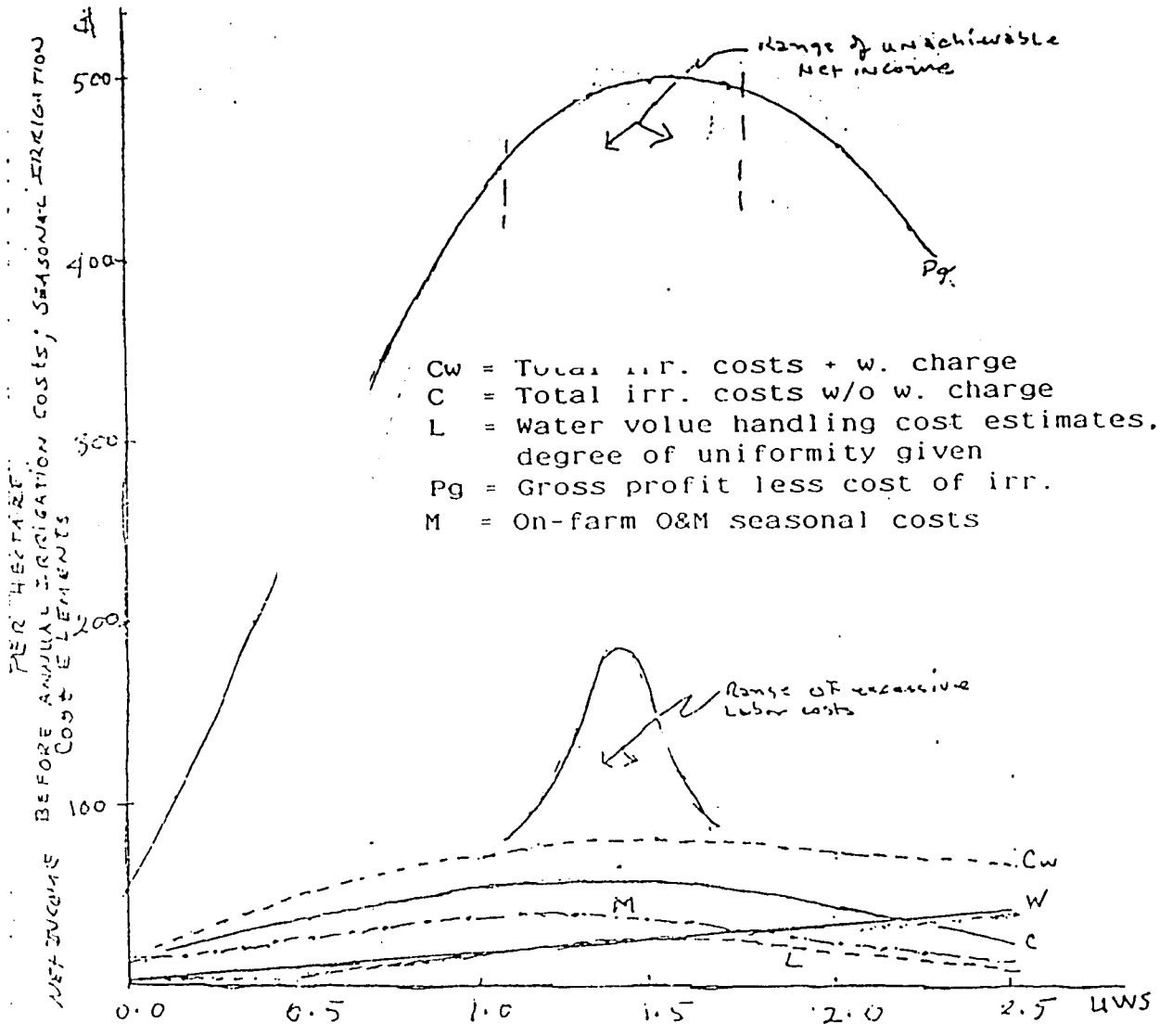


Fig. 2. Field irrigation costs related to gross profit from traditional wheat production, Maharashtra, India. Adapted from Keller, Sawant & Mulik, 1986, Fig. 2 & Tab. 1. Value of labor (hypothetical) to achieve high uniformity prevents irrigation at levels of most efficient U.W.S.

In Figure 2 the farmer's net farm or crop income (less the farm costs of irrigating) has been added. Data for wheat production in Marharshtra State in India are plotted in in this figure. A full description of the sources and computations are given in Annex A. Both the O&M and gross profit curves are taken from the wheat example. The gross profit curve is wheat revenues less production costs,

net of the costs of irrigation. Net profit is the difference between the gross profit and average variable cost (C). Some unit water charges are included and the affect upon the variable costs is indicated (Cw). The underlying production function decreases to the right of UWS = 1.5 due to water logging and is pulled down more sharply by increasing salinity. Production costs do not fall proportionately in this process, so that the net return (less irrigation cost falls even faster).

Suppose a per unit water levy can be made in this situation. This is indicated by the ray (W) from the origin in Figure 2. The sum of the seasonal O&M, labor and water costs is shown as the highest dotted curve (Cw). The labor costs shown (L) only take into account the average times necessary to apply various volumes of water at an average level of uniformity. No information is available about the special efforts that would be necessary to "spread" the water better. Except for this point it would be most profitable to operate at peak efficiency even if the water charges were doubled or tripled. However, the "costs" and "returns" in the range of maximum potential production should be ignored, they do not exist. This is shown by the hypothetical "blip" of excessive labor costs drawn centered on UWS of 1.5.

Excess Supplies. Ignoring the unattainable area, we find that, without water charges, profit near 2.0 is greater than at 1.0 (by about $50/ha). When water charges are included, profits are reduced but not by enough to cause the farmer to give up wasting water.

The economics of the traditional situation are clear. It is possible that a farmer will make more money (or minimizes his losses) on either side of UWS = 1.5. In economists' jargon, it may be better to operate in stage 3 of the production function if the water is available. In fact the farmer has little choice in the matter, he cannot operate at 1.5 even if that is the supplied amount, no matter how hard he tries. This means water is "wasted" in some cases. Remember, however, that this "waste" is utilized elsewhere, or could be.

Figure 3 contains the net profit potential for the Indian wheat example. These data reflect hand conditions with some allowance for costs to attain somewhat better efficiency in irrigation water utilization. When account is taken of the additional costs that

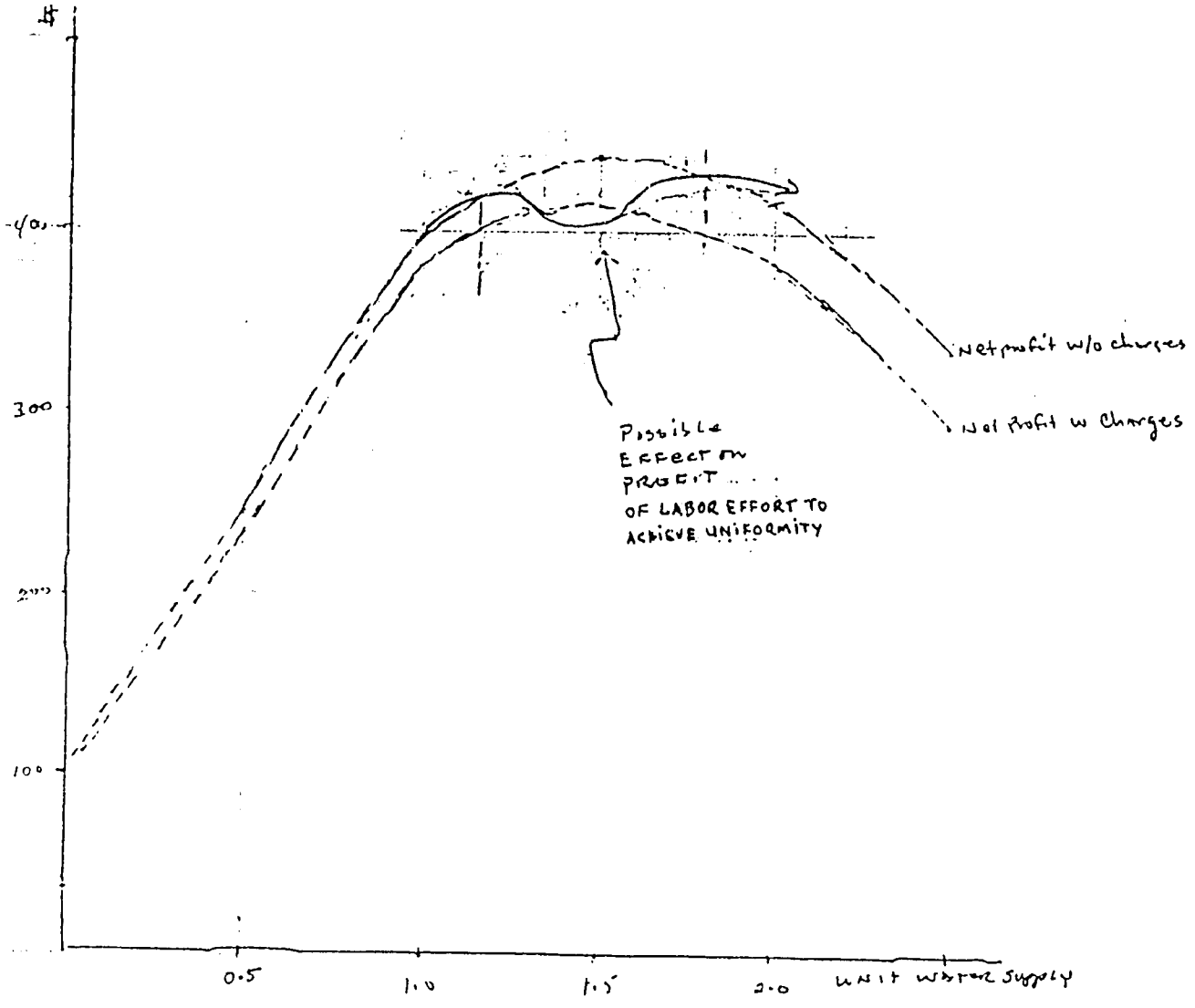
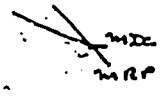


Fig. 3. Net per ha wheat profit relative to available unit water supply, India. (based on Fig. 2) UWS value not critical given average degree of uniformity implied in data. Hypothetical additional effort to achieve uniformity may be unprofitable.

irrigation turns, the interface of stage 2 an 3 of his production function will not be of interest to a traditional farmer.*

*The net returns curve can be redrawn allowing for irrigation costs in traditional system as ⌒. Since this profit function is not continuous, the negative MRP curve implied by the highest part of the right hand blip, may be negative. But it will still be cut from the bottom by a negative marginal input cost curve  where profits are maximized at the right of 1.5.

Deficit Supplies. In a sense some of this argument has been misleading, because land area has been treated as the constraining factor. In many irrigation situations there is not really enough water for the land that is supposed to receive it. Then land may be varied to optimize the value of the fixed factor, water.

In the real world a farmer that is short of water in the middle of an irrigation season will put critical supplies on the crop he most wants to save.

At the beginning of the season, however, he has a different decision to make if he thinks he will have even less than normally tight supplies. Should the water he expects to receive be concentrated on a smaller area, or should it be spread out? The general answer is well known, if we assume he wants the most return per unit of water. He will stay low on the "production function"; according to the equi-marginal rule, he will equate the returns from more than one production function as necessary. This means he will spread the water, unless experience has taught him that intra-seasonal shifts and alterations in what actually gets delivered, requires that he start off with a certain amount of water concentration in his plan.

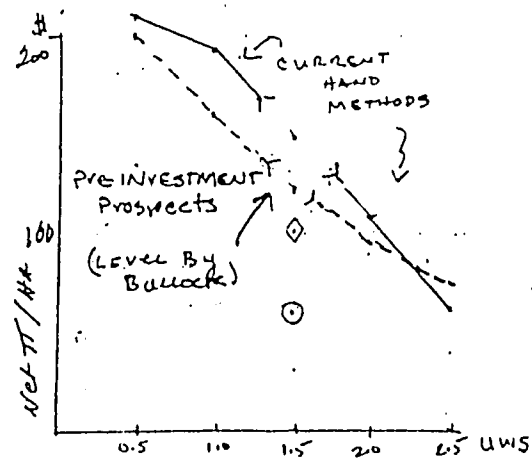


Fig. 4. Net profit per ha, varying cropped area relative to fixed unit water supply @ 0.5.

Figure 4 is based on the information contained in Figure 2 and 6a. The supposition is that the farmer expects a fixed water supply which will result in UWS = 0.5 per ha of land. (Appendix Table 2)

If the farmer applies the water at that proportion, the net return per ha (ignoring water charges) is $210. If he decides to

concentrate the area of water application until the UWS is equivalent to 2.5, he would only need 20% of his land. At that UWS value net profit per ha is about $305. Thus, 1/5 of this is $61 per ha. Again, we assume that the region near UWS = 1.5 is unattainable. The greater the effort, to be efficient, the lower the profit. See the value marked by the diamond symbol. This is a representation of the hypothetical profit if he could in fact operate at 1.5.

The lower curve in Figure 4 is based on data from Figure 6a. Depending on the type of proposed levelling investment, the area near UWS = 1.5 may or may not be attainable, or even desirable. See the hypothetical value inside the circle symbol. Unless a farmer can get above the upper curve, he will not invest.

This analysis reinforces the thought that if farmers have a fixed and tight water supply, relative to the amount of land worked, they will not invest voluntarily the time, effort and cash necessary to do efficient irrigation in traditional systems.

Machine Levelling and Other Techniques

Figure 5 shows the hypothetical relationship of investment in land levelling required to operate within a range of relative water supply. In the diagram, we see that investment in hand levelling will only be able to bring the individual farmer as close to UWS = 1.5 as 1.0. A higher investment, using animals, moves him inside that range a bit. Employing a land plane closes in on 1.5 a further amount. But to get really close he would have to invest in laser levelling.

If the farmer has a low relative water supply he will not invest anything. With more water he may be willing to level a bit more using some technique. As the relative water supply moves to 1.5, he has to invest a great deal to make use of this optimum amount. The dotted lines are mirror images of what has just been described. If he has a relatively great water supply he will not invest his labor in trying to be efficient. If the relative supply is reduced, he will have to prepare the land better in order to utilze the water more effectively. Finally in the range of UWS = 1.5, he has to go to considerable expense to be efficient with the available water.

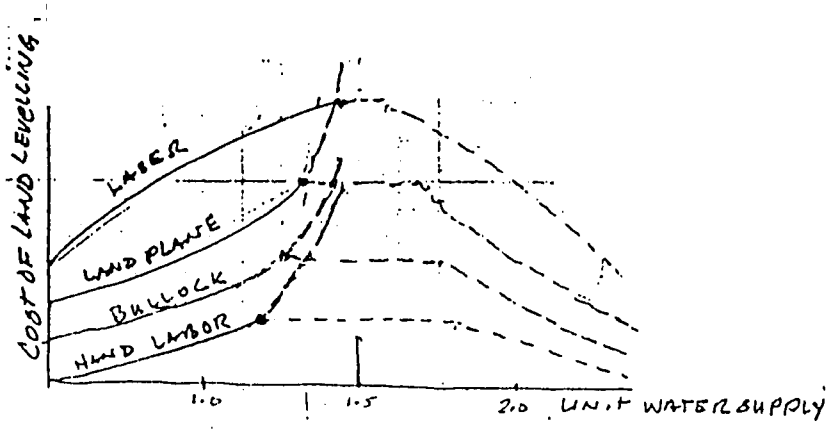


Fig. 5. Hypothetical relationship between practical upper limit on expenditures (°) and creating conditions for uniform irrigation

Possibly the laser levelling function can be treated as continuous, but it is more correct to think in terms of a "gap" for ordinary improvement techniques. The flat portion in each instance is the maximum that the farmer is willing to spend in an exponential cost situation. In fact, it is interesting to speculate that it would be cheaper to get close to the uniformity required at 1.5 by laser, than by any amount of other effort and expense.

A farmer only has two options for reducing the labor costs of doing efficient on-farm irrigation: he has to make an investment in either land levelling or in different technology.

If we think of levelling as his first option, his decision to invest will be based upon an expected jump in yields plus a reduction from current levels of his own irrigation effort, and the expectation that UWS will always be 1.5 or better. If the long-run variable costs and returns indicate higher profits from operating closer to UWS = 1.5, he will invest. If the cost is too high relative to hoped for labor cost reduction and crop increases, or if the water situation is not predictable, he will not invest.

Figure 6a shows the long-run expected seasonal return prior to investing in levelling with bullocks. The forecast annualized cost of investment intensity in bullocks is based upon data in Annex A. When these variable costs are added to those shown in Figure 2, the long-run variable cost curves (T and Tc) are obtained. The

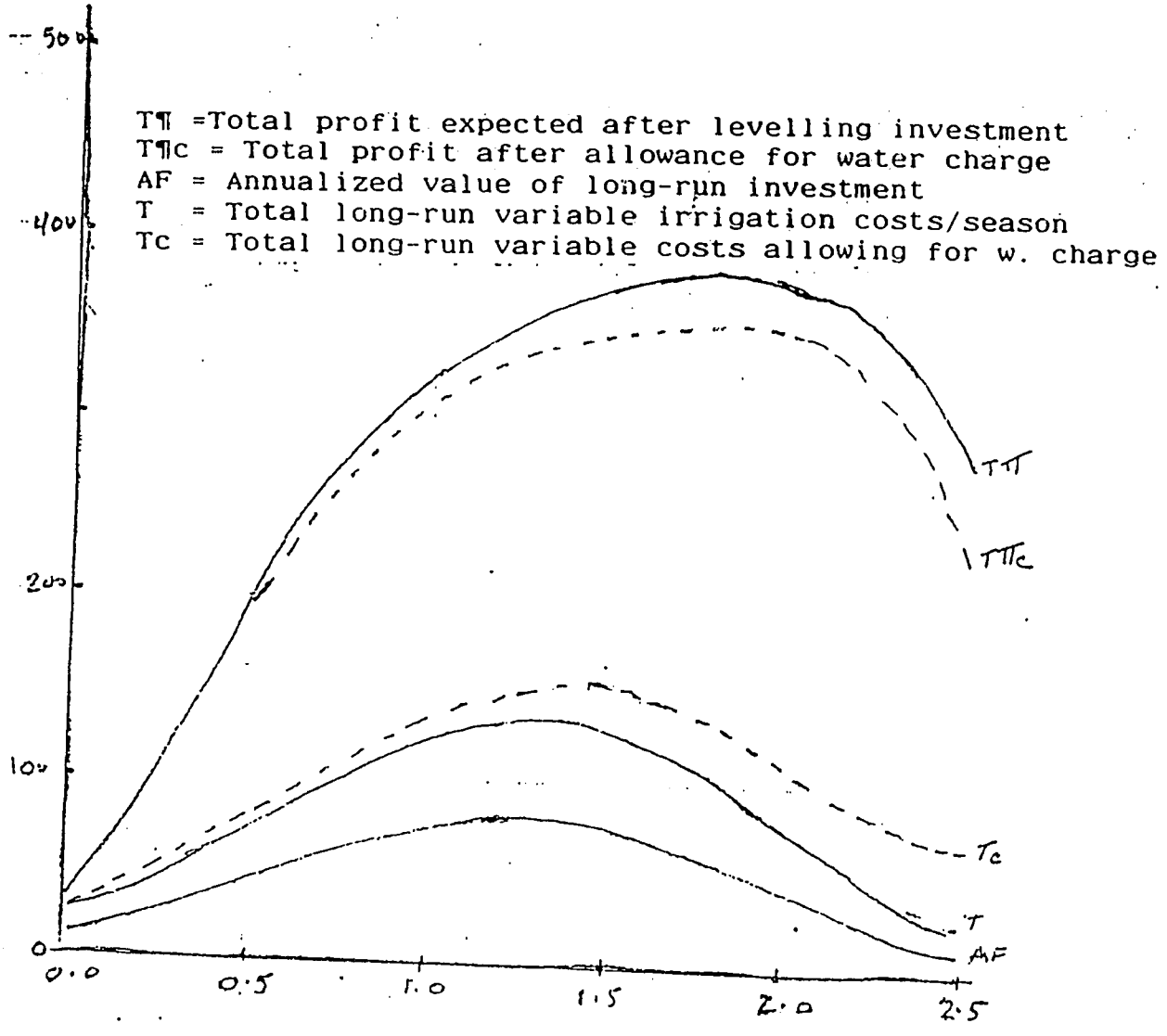


Fig. 6a. Investment planning information for levelling wheat land--India. From Fig. 3 and Annex A

relationship of T and Tc to the gross profits function in Figure 2 is shown as long run net profits potential (LP and LPc) in Figure 6a.

The wheat data shown here suggest that even if bullock investment were made it would be more profitable to stay away from the most efficient water use zone.' However, in this data, the level of information available is not sensitive enough to distinguish any particular profit point--a wide range of UWS values (if they were all attainable) would generate about the same seasonal profits.

Another element missing in the India data are estimates of irrigation labor "savings" by moving well up the technology ladder. For example, plotting the projected annualized cost of a set of

investments in various levelling technologies, along with the expected labor costs, would result in more definitive long-run variable cost and return curves for investment decisions. The result might look something like the illustration in figure 6b.

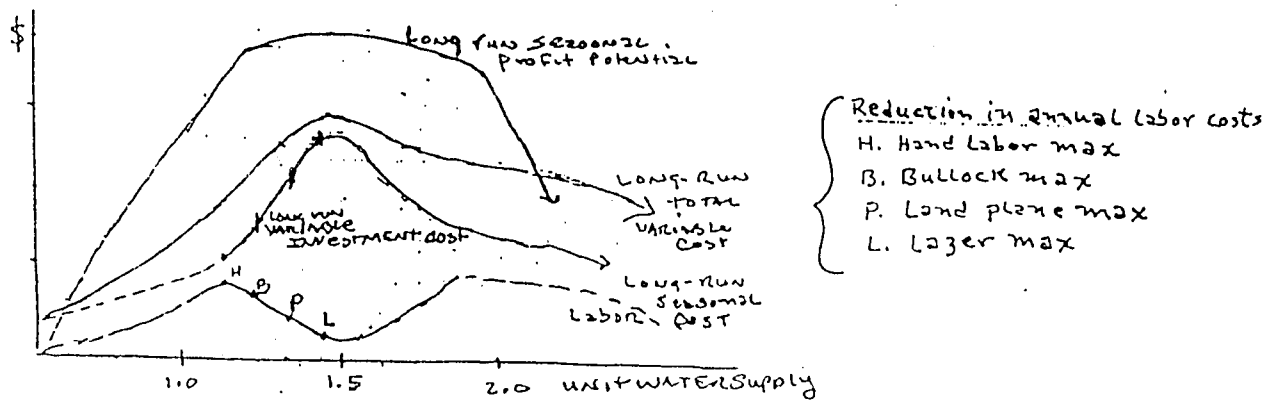


Fig. 6b. Hypothetical long-run variable costs and profit for seasonal per hectare traditional field irrigation practices

If a farmer invests, presumably he will turn back any future water deliveries that bring UWS very much above 1.5

Due to this presumption, if he invests, the short run labor cost curves will be as shown in Figure 7. Annual farm O&M cost curves will be some function of the levelling method chosen, and might still have a "hump." Annual fixed costs of the investment chosen will also be some horizontal line (discontinuous in the 1.5 zone), and will have no impact upon short-run water utilization decisions. A water fee may be imagined. The functions are not shown in any relative order.

Already it is clear that we have a few problems: farmers are not going to go through the misery of making this type of investment decision, unless the risks are very low; too much shaky information is involved.

Nevertheless, if all works out as planned, a farmer would operate at the relative water supply he programmed into his investment decison. "Excess" water will not be used in any year if he thinks production might be adversly affected. If planned for water supplies do not materialize in a given year, the combined

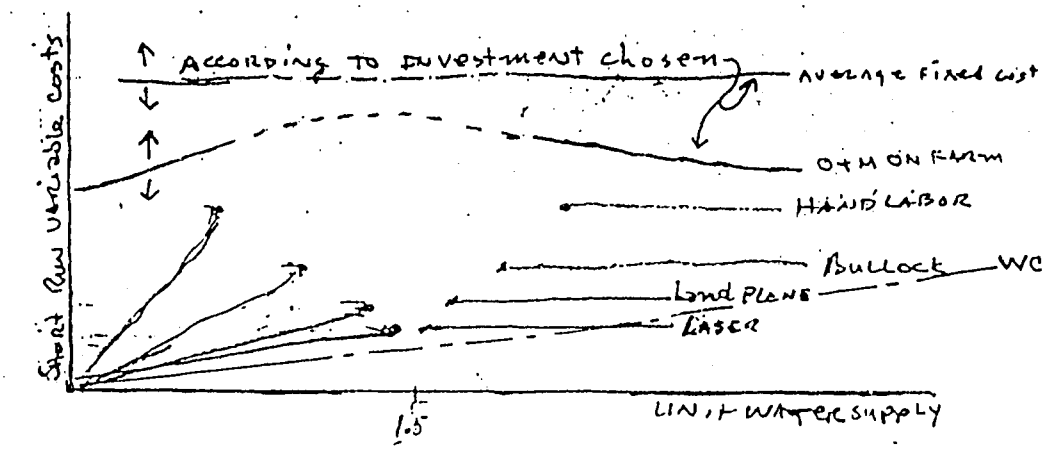


Fig. 7. Post investment short-run labor costs for traditional field irrigation in average season depending on investment choice. O&M and water charge patterned after fig. 3. Investment cost from Fig. 6b.

shapes of the water charges (volumetric) and labor cost curves, relative to his expected gross profits, MIGHT cause his to re-allocate his water utilization.

Note that once a farmer has made an investment decision, his short-run investment costs are fixed as indicated in Figure 7. Thus there is no distinction between a particular levelling expenditure, installing sprinklers, or investing in some other uniform application technology. The farmer will have a short-run fixed cost that is constant relative to UWS. Thus, in the whole zone where UWS > 1.5, he will be pushed towards greater efficiency in water use. How far towards 1.5 he will go depends on the technology level chosen during the investment process (certain levelling methods may still leave a considerable "gap" on either side of 1.5. Water deliveries temporarally received where UWS > 1.5, open up some intra-seasonal options. Depending on the relative slopes of the farmers's gross profit function and variable irrigation costs, he may or may not move toward more efficient use.

Summary

This mini analysis supports the conclusions in earlier sections of this paper. In tight water situations, farmers will be efficient in the sense that they will not waste water. This is automatic and no water fees are necessary to bring the result about. However, to say that they will not waste, does not imply that they will try to operate (in a preseason planning sense) as close to UWS = 1.5 as possible. It will not be profitable to do so. The only way that investment will be made in more efficient water handling methods is if the prospective annual labor savings and some intra-season flexibility can be gained. No farmer is going to level up land he does not have water for--But something like sprinklers might have a place.

If the farmers' regularly expected supplies generate UWS values > 1.5, they are pushed into the situation of maximizing returns to land as a fixed factor. Given excess water, in tradtional agriculture a farmer will not invest in efficient water handling methods unless the long run planning costs and returns are attractive. An example of actual data suggest that, in the India wheat case, the investment would not be made. In any event, the decision is complex and would require definitive data before any farmer would take a chance.

Even if water charges are levied on a volumetric basis, the farmer will not move closer to an efficient irrigation position than his profit picture supports--he will hold at his best option and "eat the tax." If investment in better water handling is made, yet it is difficult still to operate very close to UWS = 1.5, water charges will have some direct efficiency effects. If the water supply makes UWS > 1.5, a volumetric tax will move the farmer somewhat in the direction of greater efficiency, but in the direction of greater inefficiency if the UWS value is < 1.5. Probably a flat tax will have the same effects, only the tendency will be less certain.

REFERENCES

Hargreaves, G. H., Z. A. Samani. 1984. "Economic Considerations of Deficit Irrigation," Journal of Irrigation and Drainage Engineering, Vol 110, No. 4, December, 1984, pp. 343-358.

Keller, J., _ Sawant & _ Mulik. 1986. "Micro-economics of Field Irrigation Unpub. mimeo, Dept. Ag. & Irrig. Engineering, Utah St. Univ., July, 31, 1986.

LeBaron, A. 1984. Examination of the Purposes of Water Pricing. Econ. Research Inst. Study Paper #84-4, August (revised October 1985), Dept. Econ. Utah St

Small, L., Adriano, M., Martin, E. 1986. Regional Study on Irrigation Service Fees (mimeo, 2 vols). A final report submitted to the Asian Development Bank by Int. Irr. Management Institute. Sri Lanka, January.

Sarria, C. 1986. Irrigation Water Charges in Peru. Paper prepared for joint USAID/FAO. Sponsored Expert Consultation on Irrigation Water Charges, Rome, 22-26 September.

ANNEX A

DATA FOR FIGURES 2,3,4 & 6a

Data for winter season wheat in the central parts of Maharashtra State, India. (Based on Keller, Sawant & Mulik, 1986)

Annex Figure A was generated from Maharashtra data in a simple production function of the following form:

$$y = \sum_{i=0}^{4} ai \ (aw_i)^i$$

where

a_i = constants from Solomon (1983)

aw_i = relative available water = $\frac{AW}{AW_{max}}$

AW = irrigation water applied

AW_{max} = AW at Y_{max}

Y_{max} = maximum yield

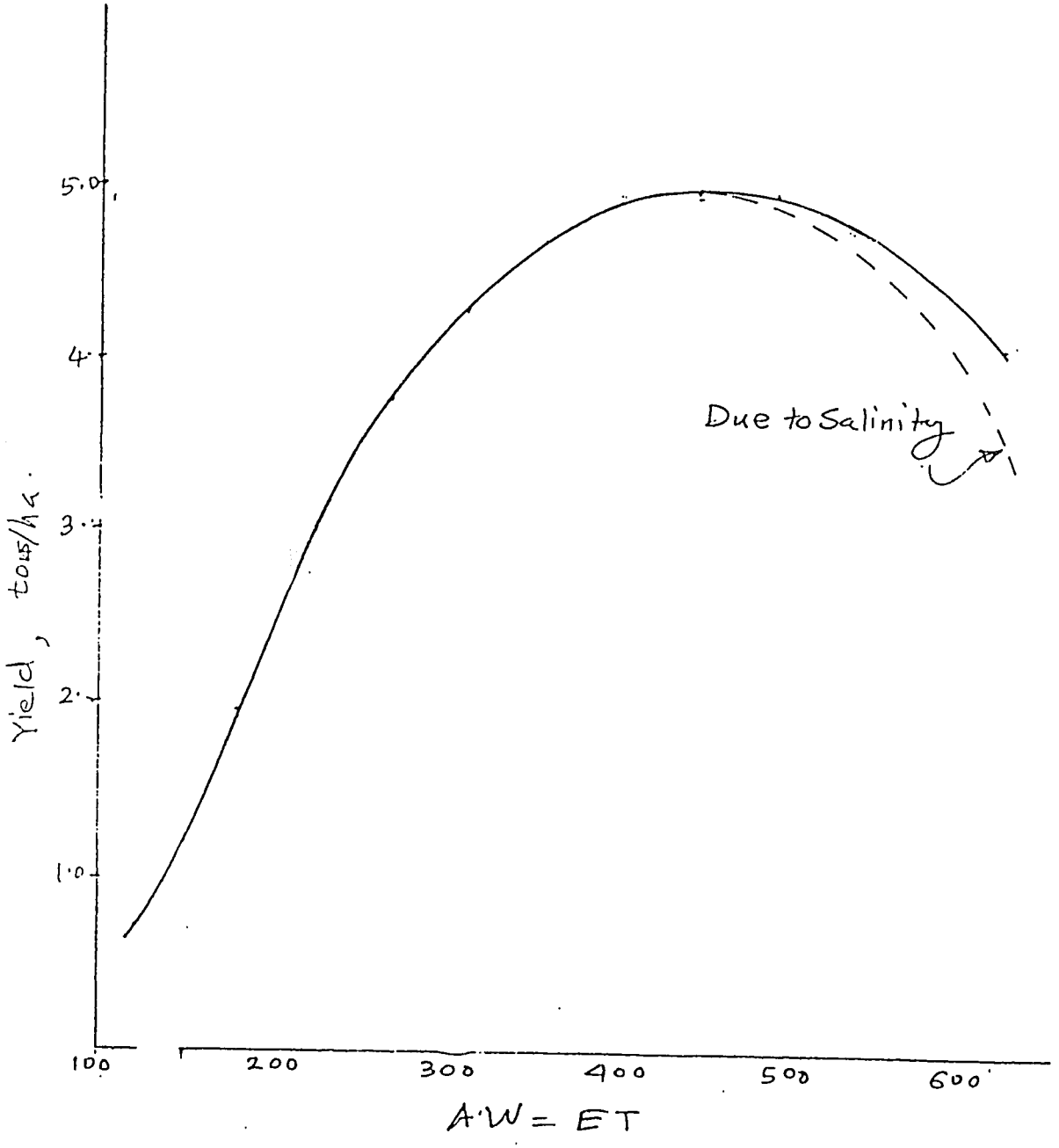
y = reliable yield = $\frac{Y_{act}}{Y_{max}}$

Y_{act} = actual yield at AW

R = efficient rain + antecedent moisture content

Assuming: Ymax = 5 ton/ha; AWmax = 450mm; R = 150mm.

If Annex Figure A is combined with data from Annex Table A, the upper curve (gross profit) of Figure 2 is obtained (assuming a peak irrigtion efficiency of 67%). Net profits are estimated by subtracting the field irrigation costs: early season touch up levelling, cleaning channels, laying out bunds and small field channels plus the labor cost of watering during the season. Some field O&M costs for tools and other hardware might be subtracted. If pumping is involved, the O&M costs on that equipment are subtracted as well (these costs would appear like an additional water charge, see Fig. 2).



Annex Fig. A. Production Function Curve for Wheat

Source: Keller, Sawant & Mulik. 1986

ANNEX TABLE A
INCOME FROM IRRIGATED WHEAT IN CENTRAL PART OF MAHARASHTRA, INDIA

AW mm	Y ton/ha	Gross Income $/ha	Cost of Cultivation Less Irrigation $/ha	Income Including Irrigation Costs $/ha
150	1.20	240	141	99
180	1.95	390	207	183
225	2.95	590	269	321
270	3.75	750	297	453
315	4.30	860	305	555
360	4.70	940	305	635
405	4.95	990	305	685
450	5.00	1000	305	695
495	4.98	995	305	690
540	4.80	960	305	655
585	4.50	900	305	595
630	4.10	820	302	518

Source: Keller, Sawant & Mulik, 1986

Explanation of Wheat Data (paraphrased from Keller, Sawant and Mulik, 1986)

1. The investment cost in levelling (see Figure 6a) with traditional bullock drawn equipment would require 800 hrs/ha at the rate of $0.15/hr, or $120/ha, whereas the refined levelling under traditional excellent methods with a tractor drawn scraper would involve earthwork of 1,000 m3/ha at the rate of $0.30/m3, or $300/ha. The traditional excellent method would also require an additional $500/ha for pipe distributon and return flow systems for conjunctive use. This raises costs to $800/ha. Assuming a capital recovery factor of 0.1, and different degrees of system perfection for spreading the water with varying levels of unit water supply, the long-run fixed cost (planning) curve in Figure 6a is obtained.

The hump in the planning curve, and in the seasonal maintenance and labor cost curves as well, is explained thus: when the water supply is very small, there is little or no benefit from precision application of the water. However, as the water supply becomes just sufficient for full irrigation to be achieved, the costs go up because the precision of irrigation must go up. Finally, the more abundant the water supply, the less efficient the system need be, and both seasonal and investment costs may be reduced by increasing the available water per unit of land irrigated. "We are confident in our argument for the reduction in (planning) costs as the water supply available per unit of land irrigated increases. Our argument for reducing costs when there is a short water supply follws the logic that if there is not enough water to fully irrigate all the land, the water (that is available) can be applied rather casually, and whatever receives water will receive full (duty) from it." (p.3)

2. The O&m costs shown in Figure 2 only include the amounts necessary to set the field up each season for irrigation, including bunds and basins and the necessary small conveyance channels. The values used are $36/ha for excellent irrigation and $12/ha for ordinary irrigation.

3. The labor costs shown in Figure 2 do not include anything for trying to do extra fine levelling by hand. The seasonal costs, nevertheless, are highest when attempts are made to irrigate at the highest practical efficiency. The labor requirements at this level are based on an assumption of handling an average stream of 10 lps. Thus, to apply a 100mm irrigation would require approximately 30 to 35 hours labor, plus set-up time. This amounts to approximately $5 /ha/irrigation at a labor cost of $0.15/hr.

For ordinary irrigation, streams of 1 lps may be used, and while efficiency is lowered, so is the labor cost. This might fall to $2.00/hr because it takes much less time to apply the water. When there is a surplus of water, the cost should be reduced even further, to approximately $1.00/hr because the workers would not need to spend full time in the fields while the water is flowing. The labor cost curve is shown as (L) in Figure 2.

4. In sum, all the cost elements have "humps" when plotted as in Figures 2 and 6a because expenses are highest at the levels of UWS where plant utilization of water is most efficient.

Figure 4 Data

Calculations for the values plotted in Figure 4 are shown in Annex Table B.

	UNIT WATER SUPPLY				
CURRENT	0.5	1.0	1.5	2.0	2.5
Profit/ha $	210	388	445	425	305
Ha Equiv.	1.0	0.5	0.333	0.25	0.20
Earnings	210	194	148	106	61

Source: Fig. 2

	UNIT WATER SUPPLY				
W/INVESTMENT	0.5	1.0	1.5	2.0	2.5
Profit/ha $	200	320	371	380	300
Ha. Equiv.	1.0	0.5	0.333	0.25	0.20
Earnings	200	160	123	95	60

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