18th International Congress on Irrigation and Drainage
International Commission on Irrigation and Drainage (ICID)
Montreal, Canada 21–28 July 2002

IRRIGATION WATER SUPPLIES TO NOT INHIBIT IMPROVED WATER MANAGEMENT

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ABSTRACT

A flexible source technology for control of the irrigation water supply and use at the farm as to frequency, rate and duration under the control of the user, is essential. It permits optimum use of the resources of land, water, weather and labor to permit improved irrigation efficiency and water and rainfall conservation as well as food production and reduction of salinity. The farmer's needs must economically be given priority.

The technique consists of the physical system and the adequate education and support in the use of the system. Neither can be neglected. The physical system includes: 1) a steady supply converted to a flexible supply by use of a reservoir reasonably close to the point of application where day-to-night fluctuations are complete, not just moderate rate variations obtained by canal storage and operation in 24-hr units; 2) the use of pipelines for distribution to permit on-farm control automatically back to a flexible source usually involving a low pressure, semi-closed pipe layout; 3) adequate capacity to permit flow rates and durations to be practical for soil intake and irrigation method requirements as well as labor cost and convenience; 4) utilization typically of a limited rate arranged-demand schedule permitting the ability with reasonable congestion, to have water when needed and arranged for, at rates not inhibiting good management, and a duration avoiding under- or over-irrigation; and 5) the incorporation of a runoff recovery return flow system that permits the on-flow rate to automatically match the infiltration rate thereby eliminating runoff.

Adequate follow-up education in the on-farm and system operation as well as appropriate funds for maintenance, must be assured, usually involving a Water Users Association. Such systems have successfully and economically been constructed.

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SUMMARY AND CONCLUSIONS

It is essential for the optimum use by any irrigation method that the water supply be flexible in frequency, rate and duration under control of the irrigator at the point of application. A water supply that is adequate, dependable, equitable and efficiently delivered may not be effectively usable. "It is not just the volume of water but the way it is delivered to make it usable that is important."

The increased yields due to management by permitting a good farmer to be an excellent farmer is the last increment for increasing world agricultural production. It takes no more land and requires less water for the farms. The physical and institutional restraints need to be removed in order for this to happen.

This paper describes systems and procedures to make it usable based on the premises: that changes are essential for improvements; that changes in irrigation supply systems are made in the delivery frequency, rate, and duration; that the control of these changes must be made by the irrigator; and that the point of control should be as close as practical to the point of application. Further, that when the supply has negligible restrictions on the irrigator who must be knowledgeable about good irrigation practices he can: conserve rainfall; mitigate excess runoff and deep percolation losses; optimize farming practices inter-related to irrigation operations; optimize crop production; and optimize labor operations including daytime only irrigation.

The physical requirements for a flexible supply system are described and questions discussed. The typical components are: an essentially constant supply source such as a main or branch canal with upstream or downstream control; laterals which may be canals or pipeline; a service area reservoir which may be located near the stable source (canal), or more economically near the center of the service area; distribution through semi-closed pipelines for stable, low pressure delivery to the farm outlets; and farmer control of the farm outlets as to rate and duration, typically used only during the daytime for high efficiency and convenience.

The flow rate capacity of the main and branch canals is the typically steady 24 hour flow rate adjustable for weather and other fluctuations and reserve capacity as needed. The lateral conveyance canals or pipelines supplying the service areas will operate 24 hours a day, but those serving smaller areas will need a larger reserve (70% to 80% congestion). The farm distributor pipeline capacity has to be adequate to supply each individual farm turnout with a large enough stream to cover a unit farm within one day (daytime only) with an adequate initial stream for high application efficiency and labor utilization (unit farm stream). The halving of the duration to daytime only requires essentially doubling flow capacity, e.g. increasing pipe diameter from 200 to 250 mm for a small incremental capital cost. A farm distribution pipeline may simultaneously serve two or sometimes three, farm turnouts and needs corresponding capacity – two or three unit streams.

The area within a distribution area must be serviceable within about half to two thirds of an irrigation cycle (50% - 65% congestion) so that there is ample reserve to permit a flexible schedule. The schedule used is a limited rate arranged-demand schedule. This requires that the irrigator arrange in advance for the desired date and rate up to the design “limit” and for the anticipated duration (volume). On this date he takes the rate needed and varies it as practical (cutback, cutoff) for as long as needed thus assuring efficient completion of a set. The use of a soil probe to follow the depth of penetration is essential to determine the best time to cutoff.

When the upper end of the on-farm distribution system is a level top ditch or a pipeline (automated) the outflow taken any place in the field is automatically matched by the inflow from the flexible supply system. This greatly facilitates setting siphons, making cutback streams or ending the set. For sloping head ditches (typical) flow variations are set at the beginning of the head ditch at the desired rate and the supply just matches.

Runoff recovery from a field is by pumping back from a small pump at the lower end with a small cycling pump that pumps back to the farm supply system at just below the flexible project farm supply gate which is operated wide open. This is just above the field control gate, i.e. between the project supply and the field control gates. Since the outflow to the field is the needed set, the return flow reduces the flexible supply rate automatically leaving the set flow unchanged, but with increasing runoff into the fluctuating level pump. The resulting on-flow just equals the soil intake rate by reducing the average flexible supply rate. Runoff from small farms can be consolidated and placed back into the supply system.

The farmer must be educated to utilize the automated supply to just match his self-perceived (educated) needs. The WUA must operate the schedule and do the negligible maintenance needed by the pipeline and robust valves.

Flexible supply project capital costs for pipelines are not cheap but are comparable to lined canal and ditch projects. The main and branch canals are simpler. Laterals may be lined ditches or pipelines. On moderate slopes, pipes may be cheaper than ditches with the reverse being true on flat slopes. The distribution systems to farms must be pipe. The cost of the service area reservoir taking about 1% of the service area is added. Maintenance, operation, and right-of-way are less. Improved good management invariably increases yields appreciably as does farming the pipe rights-of-way. It conserves water and rainfall, and reduces labor while making it more convenient. The flexible supply permits a small farmer to coordinate his irrigation with outside work. It eliminates the tailender problem and permits the farmer to grow a home or commercial garden. The total on-farm and project benefits consistently easily justify flexible supply projects. “The farm and the project are one financial unit”.

1. INTRODUCTION

It is rare that on-farm irrigation programs or water supply projects cannot be improved if management could or would make changes. Lack of knowledge of what needs changing or of how to make the changes, as well as inertia or lack of capital may be prevalent reasons for less than successful irrigation programs. Too often a project is developed and/or operated by technical people with little consideration for the application problems of the users. Both aspects, the physical and operational, must be integrated. "The farm and the project are one financial unit."

In evaluating old projects and considering the needs of new ones, it is essential to comprehend the implication of the short and long-term changing conditions created by the farming environment—nature and society. These conditions include the practical range of crops; rootzones, soils; climate and weather; labor cost, convenience and availability; capital and management skill; water condition variables as to value, cost, quantity and quality; rigid rotation schedules; water tables, environmental impacts; markets; productivity; and many others as they impose major impacts on water use problems.

The practical answer to most of them is to pass the complicated management decisions to an educated farmer but with the physical restraints removed from the system. "Don't limit the future by what is built now."

These restraints to be alleviated are embodied in the scheduling of the water as to frequency, rate and duration at the point of use. A flexible supply is essential for all methods—surface and pressurized—and all irrigated areas.

2. MODERN AGRICULTURAL IMPOSED IMPACTS ON THE WATER SUPPLY

2.1 Changes

Changes in agricultural are occurring. They impact irrigation and water supply programs. Subsistence farming becomes cash crop farming supplementing off-farm work. Long season sugar beets replace short season crops. Double cropping becomes practical. New crops are introduced or lower water use crops replace rice. Urban water demand requires more effective farm usage. Conversion of farmlands to urban and industrial use occurs. The reduced availability of low-cost farm labor imposes the need for more effective and convenient labor operations. Small land holdings are consolidated for better operations. Water tables drop from over pumping. Water tables rise from poor management.

These changes as they impact agriculture impose a need for the effective use of its irrigation related resources of land, water, climate (weather) and labor in conjunction with the resources of capital, education, research, marketing, government policy, etc.

2.2 Schedule Impact

Current irrigation programs and the on-farm application of water are realized to be improvable—to need change. The rigid or slightly modified upstream projects using rotation schedules (warabandi) prevent good water use and farm management. Conceptually, rotations schedules furnish an equal share at a constant frequency, rate and duration to each user. In practice it is not a fair share and its rigidity greatly inhibits good farm management. It, and its associated problems, are the primary causes for ineffective water use.

Frequency

Frequency should be varied to match conditions of different varieties of crops and changing seasons; weather induced changes in evapotranspiration requirements; and rainfall changing the crop timing demand; different application methods such as sprinkler wetting the total area and drip wetting a partial area; different soil available moisture and different root zone depths; etc.

Rate

Rate is related to the irrigation method and field size. Surface method intake rates are variable during and between irrigations so the supply rate should conform. The stream size should be large enough to set a whole field for labor economics, flexible enough to permit optimum initial streams and to be cut back to reduce runoff, or with a return flow system to automatically reduce the supply rate so that it will just equal the intake rate. Under rotation schedules, the rate is set to match a rotation cycle length to supply a planned volume and is not correlated to field size, intake rate or irrigation method.

Duration

Duration with restrictive schedules is set to deliver a volume (depth) related to the area of the field and not the soil intake rate and irrigation method. It should be just long enough to infiltrate the desired depth and needs odd durations and start-up times for effective irrigation.

The rotation schedule is conceptually easy to manage, but in practice by passing final responsibility down to the farmer practical problems are created: when water actually arrives down a ditch is a variable; when control is passed from one farmer to the sequential user; may be a practical problem; the top ender – low ender problem is proverbial; the seepage losses along the ditch are real and cause non-uniformity of flow rate; when the channel flow is shared adequate controls are rarely available; changing flows and applying water at night is not convenient nor efficient; the flow rate is constant regardless of the field size and irrigation method.

Because of the impacts it is essential for effective use of the agricultural resources to change from the restraints of the rigid schedules to farmer-controlled operations. The variation and characteristics of the rotation (rigid), arranged (modified, flexible), and demand (fully flexible) schedules are presented in ASCE 1984 and ASCE 1987.

The limited rate arranged-demand schedule is affordable and effective. On a day (frequency) arranged by the farmer with the supplying agency (Water Users Association), he is given authority to use the system up to the rate (limited) it is capable of delivering water and to vary the rate as he desires for as long a duration as he needs to complete the irrigation of the area arranged for.

The use of the downstream controlled limited rate arranged-demand schedule in conjunction with adequate capacity low pressure semi-closed pipelines alleviates or eliminates most of the problems associated with rigid upstream controlled rotation schedule and open channel distribution systems.

2.3 Benefits

The following three Tables illustrate the benefits from improved management upon removal of the restraints of a warabandi schedule. Table 1 (Merriam, 1987) shows how on a pilot project in Sri Lanka, with freedom to take water as practical and efficiently used in the daytime only as labor and equipment were available, less time was needed, and at least two fewer irrigations at the end were needed due to early planting.

Table 1. Percent land prepared and rice planted on the Sri Lanka Pilot Project and the adjacent conventional area (Pourcentage des superficies agricoles preparees et plantees en riz dans le perimetre de Sri Lanka, et dans les superficies adjacentes traitees traditionnellement)

Location	End of 2nd week		End of 3rd week		End of 4th week	
	Prep.	Plant	Prep.	Plant	Prep.	Plant
Pilot Project	100%	30%	100%	54%	100%	88%
Conventional	70%	11%	81%	44%	84%	54%

Table 2 (Merriam, 1987) compares paddy yields on the Sri Lanka Pilot Project and the adjacent conventional area. It shows the consistently higher production obtained due to improved water management. All other conditions were similar.

Table 2. Paddy production on the Sri Lanka Pilot Project and the adjacent conventional area (Production de paddy dans le Projet Pilote de Sri Lanka, et dans les superficies adjacentes traitees traditionnellement)

	Season	Location	Yield, kg/ha	Yield Ratio
1	Wet 1981-82	Pilot Project	2,810	2.00
		Conventional	1,400	
2	Dry 1982	Pilot Project	5,360	1.21
		Conventional	4,4410	
3	Wet 1982-83	Pilot Project	7,070	1.08
		Conventional	6,540	
4	Drought 1983	Pilot Project	0	---
		Conventional	0	
5	Wet	Pilot Project	6.980	1.11
		Conventional	6,260	
6	Dry	Pilot Project	4,620	1.29
		Conventional	3,570	
7	Wet	Pilot Project	7,190	1.24
		Conventional	5,780	

Table 3 (Merriam, 1991) presents the crop yields from four of the small farms on the Mardan SCARP Pilot Project in Pakistan. All four farmers grew wheat and sugar cane. For a third cropped area two grew sugar beets and one each grew paddy or maize. The increased yields over their pre-project yields for each of the seasons due to improved management (not more water) are extremely large. The enlargement of this 25 ha unit to the full 120 ha is being planned.

Table 3. Mardan SCARP Pilot Project average crop yields (Rendements agricoles du Projet Pilote Mardan SCARP)

Year	Crop				
	Wheat, kg/ha	Sugar Cane, kg/ha	Sugar Beets, kg/ha	Paddy, kg/ha	Maize, kg/ha
1985	950	14,000	16,800	650	930
1989	1,200	21,500	21,000	900	1,100
1990	1,750	31,000	30,500	1,500	1,600
Percent Increase	85%	120%	80%	130%	70%

The 25 ha part of a 120 ha service area gravity supplied pipeline system was converted from a warabandi to a limited rate arranged-demand schedule. Of the 120 ha earth ditch warabandi service area, 25 ha was converted to a low-pressure gravity pipeline system with a limited rate arranged-demand schedule operation.

2.4 Rainfall

In many areas rainfall provides water in conjunction with irrigation. The uncontrollable rainfall must be supplementing the controllable applied water. A rotation schedule delayed by an equivalent to the rain cannot be re-started (theoretically) to not stress some crops in the rotation. The farm just irrigated cannot store the rain and will need irrigation at its normal frequency. The one scheduled to be irrigated just following the rain (dry soil) could store all of the rain (up to the soil moisture deficiency). This rainfall could also bring all others up to field capacity. This would require that all should then start irrigating the same day one cycle later. A moderate rain would create a similar condition with only part of the farms needing to start the same day.

In practice a few days delay will only encroach on a soil moisture reserve left when the practical rotation cycle was set, but theoretically there will be a continuing deficiency with efficient irrigation.

A flexible schedule controlled by the farmers can overcome the problems and conserve rainfall. This is very important in many areas.

2.5 Labor

The restraints imposed by the rigid schedule are restrictive and are becoming more so with time. The small rigid streams coming at various times day or night and for durations related to the area, require intensive labor generally under inconvenient conditions. The greatest farmer objection is night irrigation. The inability to handle the water, and mosquitoes, snakes and cold are objectionable.

Where labor is hired, as is becoming more prevalent, the availability of nighttime irrigation is restrictive and is usually at a higher wage rate. The inconsistent duration of the work involved is not conducive to hiring labor.

Large streams at convenient times available with flexible schedules reduce the needed duration and permit time-of-day and date choice. On the Sri Lanka Pilot Project most sets were started in the morning and rarely was water taken at night or on market day. Such flexible scheduling makes it possible for subsistence farmers to schedule irrigation work to facilitate off-farm work. Home gardens also become practical.

The control of start-up times and large streams makes it possible to set several fields in sequence, thereby permitting labor to be more effective. With the trend towards farm consolidation and the use of hired labor, this becomes more important.

2.6 Irrigation Method Impacts

Waste of water during irrigation is inevitable. Excess infiltrated water from irrigating too long and application non-uniformity goes too deep and may potentially create a high water table and salinity problems. With the moving water surface methods (furrow and border strip) runoff is essential but recoverable (Merriam, 1999).

A rotation schedule delivering a planned volume (depth) to a field in a set time related to the area of the field, cannot be modified to the intake rate of the soil nor the irrigation method. Only the ponded water basin method can be adapted to the supply. This method as used has a low distribution uniformity (DU) value limited by the precision of the land grading, which under the best grading is plus or minus about 1.0 cm. This correlates to about 1.0 cm excess water infiltrated per irrigation for a DU of about 80% at best for a 10 cm irrigation. DU is almost always much lower in practice depending largely on the precision of land grading.

The following Table 4 (Hansen, 1996) presents the DU of most methods as found by many evaluations of commercial farms in California. Very few of these farms have control of duration (24 hours) but they can break it up into 8, 12 or 24 hr sets. They typically arrange for the day and a consistent 24-hour flow rate to approximately match their conditions. Most of them have fairly well graded fields.

Table 4. Average distribution uniformity (DU) of irrigation methods in California (Uniformite de distribution moyenne (DU) de diverses methodes d'irrigation en Californie)

Method	Distribution Uniformity	Std. Dev.
Border-strip	84%	14
Furrow	81%	14
Moving sprinklers	75%	10
Micro. (permanent)	73%	15
Micro. (row crop)	63%	16
Hand move sprinklers	62%	15

The standard deviation shows that all of the methods can be higher than the average values. While much of this increase for the pressurized methods will come from supervision and maintenance rather than the water supply controls, most of that for the surface method increase comes from improved control of the rate of flow, and duration from more flexible scheduling.

The furrow irrigation method is the most adaptable of all methods (Merriam, 1978; Merriam, 1999). Furrow shape and spacing are adjustable so that intake rates can be varied and consequently the desired duration. The uniformity along a furrow is related to the difference in time at the top and bottom ends (advance time), which is controlled by the flow rate and the furrow length and is affected by the duration. It is expressed as the Advance Ratio equivalent to the advance time divided by the time at the lower end.

The Application Efficiency (Merriam, 1994) of furrows is concerned with the DU and with the water losses of deep percolation and runoff. The deep percolation losses are the result of irrigating too long and are additive to those related to DU. Runoff is related to having excess flow after the water has reached the end—control of rate– and running after having reached the end, some of which is necessary—control of duration.

Furrow methods providing good uniformities (Table 4) have a reputation for being inefficient and labor intensive. These conditions are largely the result of having inflexible water deliveries. The constraints can be reduced by flexible scheduling and the runoff can be eliminated by collecting and re-using the excess water, in addition to cutting back the stream soon after reaching the end. With such improved conditions furrows are often the most effective of methods (Merriam, 1994) and low in capital, energy and labor requirements.

Border-strips (Merriam, 1994) also can be very effective if a flexible supply system is available. They are not compatible to short fields as water must be run long enough to infiltrate the desired depth while it is advancing down the strip. Short strips results in much runoff though uniformity can be high (Table 4).

Basin irrigation has only deep percolation losses which are due to the effect of the advance ratio and imprecise land grading, and placing too much water in the basin due to imprecise knowledge of the flow rate and duration—duration control. It is potentially an effective method but in practice in LDCs is inefficient and labor intensive.

With laser plane grading to plus or minus 1.0 cm elevation accuracy, a good Advance Ratio and a 10 cm irrigation, a high DU of about 80% could be expected. However with an accuracy of plus or minus 2.0 cm and a lighter irrigation, a low 60% DU can be expected with the application efficiency being lower as affected by less than perfect duration control.

The pressure methods, sprinkler and micro/drip have their uniformity built in as planned with rate as designed (not as given by a fixed schedule)—controlled rate, but appreciably affected over time by maintenance (Table 4). Their losses are excess deep percolation from running too long sets and from poor distribution uniformity and evaporation in the air.

All of these methods are described in detail in the ASCE Selection of Irrigation Methods for Agriculture by the On-Farm Irrigation Committee (Burt et. al., 2000).

2.7 Shallow Water Table Control

Rising water tables and salinity control are serious problems in many irrigated areas. Abandoned areas and restricted yields are related to the resulting salinity. Ground water quality is impacted. Often the hazard is reduced by ditch or pipe drainage systems, sometimes by pumping.

Generally speaking the excess which is largely due to over-irrigation is the result of rigid schedules and ignorance. Table 4 shows that increasing the DU from the average to the upper potential (std. dev.) could increase DU 15 to 20% and decrease the resulting excess deep percolation by 50%. There is also a potential impact from the selection of the irrigation method.

This could eliminate most high water table problems. For surface methods this could result from control of flow rates and for most pressure systems from improved maintenance and operation. For the pressure methods their application rate is also their infiltration rate so any excess duration is totally wasted deep percolation.

With the surface methods, the 'excess' is also totally wasted, but because intake rate of the soil is very slow at the end of the irrigation, the wastage is not to deep percolation but is to runoff which can be recovered in a return flow system or from runoff drains or rivers.

If the high water table is alleviated by pumping, the over-irrigation results not in water loss but in leaching of fertilizers and decreased ground water quality of the initial water supply. Deep percolation also results from seepage from open channels. The flexible water supply system involves the use of pipelines for control at the farm outlet. There is a reduction or elimination of the farm ditch seepage which can range to as high as 20% or more under poor conditions.

Where the reduction or elimination of a high water table and salinity caused by over-irrigation can be accomplished by controlling over-irrigation with a flexible supply system, the cost of such a system may be all or partially justified by reduced drainage.

3. FLEXIBLE SUPPLY SYSTEM

3.1 Objectives

The objective of a flexible supply system is to remove the irrigation created restraints that prevent a farmer from optimizing his total farming program. He must economically control the frequency, rate and duration of his irrigation, and he must be educated adequately in how to make the right choices. He must not be prevented from becoming an excellent farmer.

Such a system involves converting the adequate economical steady canal flow into the variable daytime flow needed for his operation. The assured flow must be large enough to make labor operations effective and variable as needed: for the method used, soil conditions, field size, crops grown, etc. The availability of the flow must be assured within a day or so—an arranged-demand schedule with about 50% congestion at the farm turnout (Merriam, 1997a; Merriam, 1998).

3.2 Reservoir

A reservoir to absorb the rejected nighttime flow and permit variable farm offtake flow and start-up time, is usually located near the center of a service area typically about 100 to 1,000 ha served by one canal offtake lateral. The capacity for practical operation should be large, about one-day's supply for the service area. This simplifies operation and reduces canal fluctuations and operating precision for economical system conditions. This reservoir usually covers only about 1% of the service area.

The appreciable daily water level fluctuations require consideration of the rapid draw-down problem. The appreciable dead storage may facilitate fish culture.

3.3 Distribution System Costs

The distribution system to the farm must use pipelines (ASCE, 1987). Being operated at the farm outlet, it must have downstream control. Generally semi-closed pipelines are needed for low pressure and stability at the farm turnout under variable offtake flow. The lateral lines from the canal source to the reservoir running through the upper half of the reservoir, can operate under upstream control (open pipeline or sloping canal) with operational spillage going into the reservoir as does the night flow. When replacing old earth ditch systems that often covers 3 to 5% of the service area with pipelines, appreciable land is reclaimed and seepage reduced.

The increased capital cost of flexible pipeline systems over the restrictive rotation earth ditch systems must be considered. It is often used as an objection to converting to a flexible water supply.

In the usual projects, the portion of a project above the service area reservoir—the supply system—is operated 24 hours a day and is usually an open pipeline or sloping canal. This is the program used for both the rigid and the flexible operation. Below this system, the flexible pipeline—downstream control—distribution system with its increased costs, is required.

The supply system investment is large and variable depending on the location. Many projects depend on local runoff storage reservoirs, often with year-to-year carry-over capacity to conserve the less frequent above average runoff years while others are run-of-the-river diversions. The design and capacity of the transmission system vary as does the supporting infrastructure.

The following cost illustration assumes that the investment in the supply and transmission share of a project is a low $2000 per ha; that the service area distribution system requires 50 m per ha of listed size and capacity pipe (refer to Table 5); service area reservoir takes about 1% of the area to store one-day's water supply costs $100 per ha served; the advantage of farming the distribution pipelines right-of-way compared to the alternate 3 to 5% land taken from farming by using ditches requiring maintenance is ignored; also ignored is the lesser capital needed for the main canals due to simpler flow controls needed because of the service area reservoir's function.

Table 5. Relative pipeline and open channel sizes, capacities in streams of 27.8 lps, and cost [50 m/ha] (Comparaison des dimensions de conduites et canaux a ciel ouvert, et debits correspondants [pour une main d'eau de 27.8 l/s], et couts relatifs [50 m/ha])

Item	Pipe				Open Channel	
	150 mm (6 inch)	200 mm (8 inch)	250 mm (10 inch)	300 mm (12 inch)	Earth	Lined
No. of streams	.5	1	2	3	.5	.5
Cost, $/ha	200	250	290	350	50	200

These various pipeline capacities are combined in Tables 6 and 7 to show various degrees of flexibility and their corresponding capital and annual costs at 10%, which is essentially subsidizing water charges. Maintenance and other charges are omitted for simplicity.

Table 6. Illustrative distribution system descriptions from rigid to flexible (Examples comparatifs de modes de distribution, allant du mode fixe au mode souple)

Item	Description
a.	basic elementary earth canal, warabundi
b.	basic elementary lined canal, warabundi
c.	basic elementary 150 mm pipe, warabundi
d	service area reservoir with 200 mm pipe, daytime warabundi
e.	service area reservoir with 200 and 250 mm pipe, flexible supply at moderate congestion
f.	service area reservoir with 200, 250 and 300 mm pipe, flexible supply at low congestion

Table 7. Illustrative cost and benefit analysis of a flexible water supply (Couts et benefices d'une alimentation en eau selon le mode souple)

Item	Total Capital Cost, $/ha	Annual Cost, $/ha
a.	2,000 + 50 = 2,050	205
b.	2,000 + 200 = 2,200	220
c.	2,000 + 250 = 2,250	225
d.	2,000 + 100 + 250 = 2,350	235
e.	2,000 + 100 + (250 + 290)/2 = 2,370	237
f.	2,000 + 100 + (250 + 290 + 350)/3 = 2,400	240

Table 7 shows the well-recognized value of investing capital to increase benefits. Going from **a** with its maintenance costs and lost farming land and seepage to **c** with negligible maintenance and loss to seepage plus 3 to 5% increased area is possible with an increased cost of the magnitude of $20 per ha per yr. This is a similar situation to investing in fertilizer to increase yields.

Going from **c** with a warabandi schedule, to **d** doubling capacity eliminates nighttime irrigation for $10 per ha per yr. Going from **d** to **e** or **f** eliminating congestion makes possible the truly upgraded management potential for the magnitude of $15 per ha per yr. This is equivalent of 20 kg more cotton per ha. Going from the minimum condition **a** to the optimum **f** saves seepage and land area used for water courses, eliminates night irrigation and saves labor, permits optimum on-farm water management and so increases yields and saves water, perhaps eliminating drainage and salinity problems. These benefits and many others could be obtained for about $35 per ha per yr. If an irrigation project is justified, it is justifiable to do it by removing restraints to optimization for a small additional investment.

3.4 Runoff water recovery

With moving water surface methods, runoff is essential while adequately irrigating the lower end of a furrow or border-strip. It may be modifiable by cutting back the furrow stream to reduce runoff or by ponding at the lower end or by recovering the runoff. A small sump and cycling pump at the lower end of a large field or a group of small fields can return water to the flexible supply system at or near the point of delivery. This will automatically reduce the delivery flow by the same amount making the supplied rate match the soil infiltration rate.

4. INFRASTRUCTURE TO SUPPORT A FLEXIBLE SUPPLY SYSTEM

Warabundi and similar rotation schedules are imposed top-down and require little communication between the water agency and the farmer. They do require close personal contact among the farmers when handing over the flow to the next user. This is frequently a point of conflict.

The flexible schedules require effective communication. The practical desirable limited rate arranged-demand schedule requires that the farmer arrange the date(s) with the supplying agency and possibly a limit on the rate when there is more than one user on the distributor. The limited rate is set at the design capacity of the line, usually one or two streams (users), or by the turnout capacity.

On the arranged date the farmer operates his turnout on-demand as to rate and duration to match his specific needs. The agency needs to see that the system capacity is not exceeded and that the supply from the canal and the demand from the service area reservoir is balanced. These are all simple water management procedures mostly being done by the farmers from an automated system.

The WUA must additionally handle the usual administrative, financial and maintenance functions and especially education of the farmers in utilizing the flexible water supply on their farm. It must see that its relationship with the related governmental agencies works cooperatively to provide a service to farmers.

5. CONCLUSIONS

The preceding presentations have shown the value of the flexible, management compatible water supply in alleviating the irrigation induced restraints of the rigid supply schedules. It optimizes the use of the resources of land, water, climate and labor. Water is more effectively used with less running off or going underground with reduced quality. Quantity and quality of crops are increased through better on-farm management and with less water needed. Increasingly expensive labor is reduced and made more convenient. High water table and salinity conditions are substantially reduced permitting reclamation of lost production.

With these and many more benefits, it is very important to realize that with the reduced irrigation water and land resources due to competing urban, industrial and environmental uses that increased production per unit of water and land made possible by improved management is the last increment of food production to feed an increasing population. The irrigation induced restraints must be removed so that the average and good farmers can become excellent farmers. Increased production due to improved management is the last increment available. “Don’t limit the future by what is built now.”

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