EXPERIENCE WITH FLEXIBLE SCHEDULES AND AUTOMATION ON PILOT PROJECTS

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ABSTRACT

Worldwide the on-farm water management restraints created by rigid water supply schedules cause problems of inefficient irrigation and rainfall use, high water tables, lowered production, increased and less convenient labor, complicated cultural operations, and increased costs. In the USA a beginning is just being made to modify the fixed flow rate/24 hour duration schedule to permit farmers to adjust the flow rate and duration. In developing countries frequency as well as rate and duration are usually fixed with rotation schedules. Because of the small farm sizes durations of the fixed stream vary in proportion to the farm area and not the soil intake rate nor antecedent rainfall. The rotation stream is delivered at inconvenient times and the flow rates are rigid and usually too small for practical management and for labor efficiency. High water tables correlate with inefficient irrigation.

Pilot Projects designed with: adequate short-term storage to accommodate large variations in flow rate which are often greatly reduced at night; with automated canals and pipelines capable of responding to downstream farmer initiated flow variations; and with large variable streams to greatly reduce irrigation time and labor, can be used to demonstrate the value of flexible arranged or demand schedules having only economically non-restricting controls on frequency, rate, and duration.

INTRODUCTION

A small but enlarging program has been carried on for a number of years to educate engineers, farmers, government officials, policy setters, and others of the necessity of having a flexible water supply delivery schedule at the farm level. Pilot projects have been used to assist this program. Much research and development work has been done in improving on-farm irrigation equipment: sprinkler, trickle emitter,

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surge flow, etc. Much has been done to improve scheduling of water application and refining techniques for determining the evapotranspiration or soil moisture deficiency. Procedures to determine irrigation efficiency and uniformity are beginning to be applied on the farm.

A common factor for all of this research is that it is developed with the intent of improving water use, or of making something that can be sold that will save water or labor. It is presumed that the farmer will utilize the information or equipment. In practice this use happens only under unusual conditions with center pivot sprinklers and trickle being major exception to a large extent because something is for sale as well as being practical. It is a common comment by technical people that the farmers just don't do a good job -- if it is good enough for grandfather, it is good enough for me. The real condition however, is that generally they cannot do it even when they are aware of improved procedure. This is true because almost all of these refined techniques involve a modification of the frequency, rate, or duration of flow, a condition which frequently can not be attained because of restrictive schedules.

The scheduling restraints put on the manageability of the applied water have been accepted, but not adequately realized nor challenged. Until the farmer can control the frequency, rate and duration of the water supply, he cannot be an effective manager. A well designed sprinkler system that applies a designed depth in a set time convenient for labor, e.g. 12 hrs., can seldom match a desired depth unless frequency is a variable during the season. Or if frequency is set because of farming operations, it can seldom match the desired condition unless duration is a variable. Or changing root zone depth needs cannot be matched unless duration and frequency are variables. For surface irrigation the changing intake rates during the season and different application depths require that duration be a variable, and that the flow rate be a variable to match a desired set size. For developing countries with rotation schedules, it is not realized that it is impossible for a farmer to be more efficient than the design value with its fixed assumptions since the water supplied is fixed. If the farmer wished to improve his efficiency, water could not be saved unless he could take less which he cannot do unless he is given control of the supply.

Only by educating the farmers which they desire to have done, and giving them control of the frequency, rate, and duration can effectiveness of irrigation be upgraded. Improved labor has the same relationship to upgraded scheduling, it cannot be made better without schedule changes. It is especially important to have a large stream to shorten labor and have variable convenient durations to avoid most night irrigation and conform to available labor.

The 24 hour duration arranged schedule prevalent in the USA, puts appreciable restraint on the irrigation manager which is accepted because it is not realized that it can be modified in a practical and economical way. Though he may arrange the frequency and stream size on many projects, the fixed duration relates to a specific stream size so that the delivered depth reasonably matches the soil moisture deficiency condition and irrigation efficiency. The resulting stream size seldom is the best for the set size. To have the set durations which should be related to intake rates always equal a 24 hour unit is improbable. The compromise with convenient labor and the water supply is lower irrigation efficiency with non-uniform infiltration and runoff. Set durations of 8 or 12 hours for convenience of labor dominate rather than durations related to intake rate and soil moisture deficiency which do not correlate with 24 hr increments and specific frequencies so efficiency suffers.

It must be realized that until the manager can control the irrigation frequency, rate and duration, he cannot optimize his management program. He cannot make irrigation a coordinated aspect of the total farm program of cultural operation, irrigation method, crop production, water use efficiency, labor amount and convenience. Until the frequency can be set to match the desired management allowed soil moisture deficiency <u>**or**</u> the convenience of labor relative to the total farming operation, production or expenses must be compromised. Until rate can be controlled to optimize set size, match intake rates, utilize labor fully, conform to desired method needs, control efficiency, reduce runoff or deep percolation, etc. operation costs will be excessive. Until duration can be controlled to turn off the water when enough has infiltrated, water will be wasted and a high water table may be created. Restraints on the schedule impact management capabilities. The alleviation of scheduling restraints must become a major objective of those associated with new irrigation projects or the rehabilitation and upgrading of old ones. Adequate knowledge and experience exists to incorporate the needed changes even though it is not widely known. Pilot projects may be needed to provide local experience but they should not be used as an excuse to delay the implementation of current information.

One of the long term objectives of the On-Farm Irrigation Committee of the ASCE is: Bring awareness of the on-farm irrigation needs to the larger civil engineering profession who do designs of irrigation projects in a conventional way without adequate knowledge of on-farm conditions.

SCHEDULES

Schedules of water delivery are the expression of how water is made available to farmers. Restraining, rigid schedules restrict farm management capability. The rotation schedule rigid in all aspects of frequency, rate, and duration is common in many developing countries. If forces inefficient water and labor use and restrains production. The common schedule in the USA is the 24 hour duration limited rate arranged schedule. It appreciably restricts labor and water use efficiency and not infrequently limits crop production. It is an accepted schedule and its restraints are not often realized and challenged. However in some areas such as Coachella Valley, many farmers have installed reservoirs for 40 and 80 acre (16 and 32 ha) units to facilitate labor and management operations more than for water conservation. By so doing they can convert the small stream, 24 hour supply schedule to a demand schedule with a large flow rate, often four times larger than the supply rate, with a corresponding reduction in irrigation labor time and an increase in irrigation efficiency.

The broad classifications of schedules as listed by the On-Farm Committee of the ASCE (ASCE 1984) and in the ASCE Symposium Proceedings "Planning, Operation, Rehabilatation and Automation of Irrigation Water Delivery Systems" (ASCE 1987) are: Rotation with preset conditions of frequency, flow rate, and duration; the Arranged modifiable between the rigid and flexible arranged schedules and which requires a communication system between the supplier and the farmer to arrange the restraints; and the Demand schedule in which the farmer takes water as he desires without a need for communication. The Demand, and the Arranged schedules, to be practical, need to have a restricted upper flow rate limit. This limit is usually physically imposed by system capacity, but it should not be appreciably restrictive of the farm manager's optimum operation or the value of flexibility is reduced.

The desirable and practical schedule has an arranged frequency, limited but large rate, and unrestricted duration within daily units. It is practical and essentially non-restraining on the farmer to have his anticipated rate and variations and the duration noted at the time of arranging. It may be that he might plan a moderate stream only during the morning so another user could be accommodated in the afternoon, or be allocated a moderate stream at the same time. The arranging procedure enhances system usage. Reserve capacity for large variable streams should be designed into the system so that the farmer is guided but not precisely restrained at the anticipated arranged limit so that his management is not impaired.

FLEXIBLE SYSTEMS

Upgraded schedules invariably permit reducing the water and labor needed and, because of the better on-farm management made possible, can enhance crop production. These benefits at the farm level can justify more capital investment to upgrade the project capabilities--"the farm and the project are one financial unit." A representative increase in project efficiency is from 55% to 70%. Often the change is much greater. This implies that the average flow rate can be reduced where flexible schedules are introduced. However, it must not be used to imply that the peak rates may also be reduced. It is the variable and increased peak rates and the modified duration's that are the heart of flexible scheduling.

With the introduction of management input into scheduling, one of the first items it is desired to change is the elimination of night time operation. This is largely due to labor being inconvenient and increasingly difficult to obtain and the reduced capability to efficiently handle the water and observe crop conditions. The elimination of night irrigation essentially requires the doubling of the flow rate. Also to obtain reserve time to facilitate modifying frequency means that flow capacity in the lower part of a system should have nearly four times the steady flow rate of a rotation schedule. Further consideration indicates that the stream should be large enough to keep the irrigator economically busy and be able to make irrigation sets that essentially cover a whole field at a time. These are considerations the engineer must have in order to plan a project while "thinking like an educated farmer" to economically provide what is needed to not have irrigation restraints impede effective farm management. It must be realized that "it is not just the volume of water to be delivered, but the way it is delivered to make it effectively useful" that is important.

The system to accomplish this must have a source such as a reservoir to permit variable withdrawals. It may be the year to year supply reservoir. However, for operation flexibility it should be located reasonably near the final point of delivery so there is negligible lag when needed. This condition usually requires additional local storage facilities. It may be in-canal storage. It may come from an improved on a distributory or even on a farm, or in other ways. The larger such storage is and closer to the delivery points, the more simply and uniformity the supply system can be operated and hence be smaller.

For illustration, a reregulating overnight (12 hr.) storage reservoir for a 1000 ac (400 ha) service area to satisfy .42 ipd ET at 70% efficiency which requires .60 ipd (15mm/day) would need to store

$$\frac{12 \text{ hrs.} \times .60 \text{ ipd}}{24 \text{ hrs.} \times 12''} \times 1000\text{ac} = 25 \text{ ac. ft.} \quad (3 \text{ ha m})$$

For ease in operation it should store more, say 50 ac. ft (6 ha m) to permit a nearly steady inflow and have adequate reserve. If it were located near the center of the service area and had steady inflow which could be utilized in the upper half during the daytime it would need only about half the storage capacity.

5.0 ac. x 5' deep in a 1000 ac service area.

Such a reservoir can be gravity or pump supplied or emptied. The reservoir and land might cost $50,000 ($50/ac) and have an annual cost of $6.00/ac/yr ($15/ha/yr.). It could permit a very flexible schedule but a very steady flow in the main canal. Such systems are essentially ones in which the operational spillage from the upper area is reregulated for the next days use downstream. They provide a very simple technique for automation.

Increasing pipe system capacity and automating them for upgrading projects to flexible schedules, or in new designs, is economical in most cases when the on-farm benefits are considered as well as project benefits. For illustration: A sub area of 250 acres (100 ha) that could be operated (1) On a Rotation steady flow 24 hours/day schedule with one stream with 12 hour sets might require 8" (200 mm) diameter pipe. (2) It could be converted to operate daytime only using a 10" (250 mm) pipe in the upper half to use one and transmit one stream there and use the second stream in the lower half. This would require a 7% increase in cost. It would still have to be a rigid 12 hour schedule but no night time irrigation would be needed. (3) If capacity in the lower part were also doubled by using 10" (250 mm) the entire length and two streams were delivered at a farm turnout for 6 hours in the upper half and then for 6 hours in the lower half on a rigid schedule, the irrigation labor time would be cut in half for an increase of 14% in pipeline capital cost. (4) To provide a flexible two stream capacity system to up to two farmers simultaneously would utilize the system only half the daytime periods supplying appreciable reserve for flexibility. It would use 10" (250 mm), 12" (300 mm), and 14" (350mm) pipe each for about one third of the length for a cost increase over 8" (200 mm) all the way of about 44%.

To illustrate relative cost. If the systems used 66'/ac of pipe (30 m/ha), and the 24 hour rotation using only 8" (200 mm) pipe cost about $225/ac ($560/ha), and a capital recovery factor of 12% is used, Table I provides a comparison of the costs of the pipe distribution for various schedules.

Table I. Relative Costs

	Schedule		Capital Costs		Annual Costs	
		Percent	Per acre	Per hectare	Per acre	Per hectare
(1)	24 hour rotation	100	$225	$560	$27	$67
(2)	12 hour rotation	107	$240	$600	$29	$72
(3)	6 hour rotation	114	$255	$635	$31	$77
(4)	6 hour flexible	144	$325	$810	$39	$97

While Table I does not include all the costs for the various conditions, the distributory system pipe is the major variable as a dam and reservoir and main canal systems costs are quite similar for all alternates. These costs need to be considered from the view of a farmer who must ultimately pay them and who would think of them in terms of an annual increased water charge.

To compare (1) and (2) which only removes the night time use requirement, the annual charge to be added to the water charge for this is about $2/ac/yr. ($5./ha/yr) which any farmer would be willing to pay to avoid five to fifteen night time irrigations a year.

Comparing (1) to (3) which reduces the labor to half and also allows daytime only operation, the annual cost increase is $4/ac/yr. ($10/ha/yr). Such daytime operations would probably result in increased crop production but could not result in more efficient irrigation because no less water could be delivered with the rigid schedule.

Comparing (1) to (4) permitting flexible streams has consistently resulted in increased crop production, reduced water use, and reduced labor and made it more convenient. The annual cost for upgrading the pipe distribution portion of this project is about $12/ac/yr ($30/ha/yr).

CASE STUDIES OF FLEXIBLE SCHEDULE APPLICATION

These case studies from in the USA and developing countries illustrate application of various techniques to make possible the use of upgraded, more flexible irrigation delivery schedules with more control by the farmer as to frequency, rate, and duration. They report obtaining variable flow rates from different sources and by different techniques: direct from reservoirs; varying in-canal storage; on or beside the canal reservoirs; elevated terminal reservoirs; operational spillage in sloping canals reregulated or wasted; automated level top canals; elevated and depressed canals; supervisorial control of canal flow rates and storage; semi-closed and closed low pressure pipe lines; farmer controlled farm turnouts; flexible arranged schedules; low lift portable or fixed location pumps; high pressure automated pumps to elevated terminal reservoir.

Orange Cove Irrigation District, California, USA.

This 28,000 ac (11,000 ha) irrigation district (Chandler, et al 1990) (Merriam, et al 1990a) in the last few years has started a rehabilitation and upgrading program. The former 24 hr. limited rate arranged schedule operated by district personnel is upgraded to a limited rate arranged one with the available rate nearly doubled and the farm turnout gate being operated by the farmer during his arranged day or days. The former fixed rate is now variable. The water volume delivered is no longer a rate for 24 hour computation, but is measured by an in-line totalizing meter directly connected into the district main line and read once a month. The day and anticipated rates and duration are arranged a day ahead of use as was formerly done, but modifications are freely made by the farmer during the day.

For booster pumps on the farm it is now possible to take out water to exactly match needs at the desired pressure to operate the sprinklers at optimum conditions and for just the duration needed. It is now possible to have a runoff return flow cycling pump system return water directly into the farmer's closed low pressure field pipe line. The inflow to the pipeline from the district will automatically be reduced to maintain the set rate being applied on the field. Large initial and cut back flow rates can be set and the project delivery rate will continue to automatically match the rates applied to the field. All such variations in the lower service areas are automatically made back through the on-farm system through the meter and district's semi-closed float controlled pipeline (Merriam 1987a) system back to the Friant-Kern canal supply. Here the minor changes are absorbed by in-canal storage fluctuations.

The use of small in-canal fluctuations is made possible by the cooperation of the Friant Water User's Authority which took over canal operation a few years ago from the US Bureau of Reclamation. It is anticipated that similar upgrading programs will develop among the other district members of the Authority along the canal.

On the upper service areas above the canal, water is pumped to terminal reservoirs about 100' (30 m) above. Pumping can be concentrated during favorable power load conditions and as needed. The desired farm off takes are automatically supplied from the reservoir and pump.

The increased capacity and farmer controlled variable rates will reduce and make more convenient the on-farm labor needs and increase irrigation efficiency. In this water short project, this will provide the equivalent to 5% to 15% more water. A quotation from a letter from Engineer-manager James C. Chandler says, "I'm happy to report the unbelievable support I've received from the growers in the District." These are the people who are paying all the costs on the project and the farm.

Imperial Irrigation District, California, USA.

This District (as reported elsewhere in these Proceedings) has established a 17,000 ac (6,800 ha) pilot project. Here it will be possible for the irrigator to turn off the flow to the farm when he has applied enough water using a flexible duration rather than the previous 24 duration arranged schedule. Previously the irrigator was not confident of always being able to adequately complete an irrigation. This was because start up and shut off times often were an hour or so different than planned so the duration could vary appreciably from the planned 24 hours. Also the flow rate and the farmer's estimate of the needed water were not precise. To be sure of adequately completing the irrigation, as much as 10% excess water was arranged for.

With the introduction of a flexible duration arranged schedule, the irrigator is always sure of finishing the set so no excess flow is needed. This upgrading of the schedule was accomplished by having flow in the lateral excess to the arranged flows and collecting and reregulating the variable operational spillage in a reservoir for use later at a lower elevation. This is one of the simplest techniques for automating flow changes in sloping canals.

The objective of the variable duration schedule was to conserve water. It will be practical to extend the schedule to permit flow rate changes within limits as arranged. This will make it possible to match stream sizes to conform exactly with what is needed under varying conditions on the farm to improve irrigation efficiency by reducing runoff and deep percolation.

Later it will be possible to convert the farmers' distribution ditch to a level top downstream float controlled ditch or use a closed pipeline. With these techniques flow rate changes made in the field will automatically be matched by inflow changes at the lateral. Also cycling return flow systems can be pumped back to such a head ditch and the farm onflow rate will automatically be reduced by the same rate to provide a stable farm turn out flow rate. (This is the same capability for canal irrigation as described for the Orange Cove Irrigation District semi-closed pipe line system.)

<u>Gadigaltar Tank Irrigation Pilot Project, Khargone, Madhya Pradesh, India (Merriam, 1990 b) (Merriam, 1991).</u>

This project, construction of which has just been completed, supplies water to over 550 small farms on about 2,900 ac. (1150 ha) through 38 miles (64 km) of low pressure semi-closed (Harris float valve) concrete pipe system. It is an automated system permitting about forty to sixty farmers a day to operate their turnouts under a limited rate arranged schedule. Because of the project size and complexity, many techniques are used to simplify controls. The most involved aspect of the project is making the many contacts to arrange the numerous deliveries. This is done through a hierarchy of 76 contact men, each representing a group pipeline. They consolidate water orders into 10 locations which are then transmitted daily to a central office. In the system operation the only manual operation is to make a morning and evening setting of the storage reservoir outlet gate into the 3.0 mile long (5.2 km) sloping main canal to correspond to the water orders.

From this sloping canal, which always has water flowing through it with a planned operational spillage dropping into a reregulating secondary reservoir, supply pipelines take off to serve group areas of six to ten farms zero to three of which may take water at a time as arranged. Below the reregulating reservoir which has storage capacity for a day's flow to the area below it, a .6 mi (1.0 km) long level top canal maintained constantly full at a stable elevation at its upper end by an AVIO Neyrtec float controlled gate, supplies water to four large semi-closed main pipe lines feeding many supply pipelines serving the group areas.

The system has capacity to serve all the farm groups in five to seven ten hour days. The expected average irrigation frequency is about ten days to two weeks so there is appreciable reserve in unused days and extended evening hours to provide a flexible schedule.

The total cost of this 2900 acre project with its large 5600 ac. ft. (900 ha m) storage reservoir, 38 mile (64 km) pipeline system and appurtenance secondary reservoir, canals, etc. was close to $3,000,000 ($1,000/ac). Of this the distribution system cost was about $1,000,000 and the pipe itself about $350,000. A study to reduce the pipeline capacity to about one half which would lose the flexible schedule capability but not the daytime only ability showed the pipe cost would reduce to about $250,000. This cost saving of $100,000 represent about 3% of the project cost. At a 12% capital recovery factor, it corresponds to $4/ac/yr. ($10/ha/yr.), out of an annual project cost of about $120/ac/yr. ($300/ha/yr.), a negligible saving for the major benefits lost.

As the result of this pilot project, the Water Resources Department of Madhya Pradesh is recommending the use of pipelines as being more economical and desirable than small lined open channels formerly used for water distribution to farms.

<u>Sri Lanka, Demand Irrigation Schedule Concrete Pipeline Pilot Project (Davids, et al 1990) (Merriam, 1987b, 1991).</u>

This 375 ac. (150 ha) project using semi-closed low pressure concrete pipelines supplied by flexible sources had consistent paddy yield increases of 20% which was adequate to repay the cost of upgrading in two crop seasons.

<u>Pakistan, Mardan Salinity Control and Redamation Project. (Merriam 1991).</u>

This 40 ac (16 ha) first stage pilot project used 4,000 ft. (1200 m) low pressure concrete pipeline fed from a 500' (150 m) sloping lined canal converted to a level top by addition of a wedge on the top and maintained constantly full by a direct connection to a distributory canal. Yield increases were major being about 40% with up to 60% for the paddy where improved water management was very effective. As reported by the Supervising Engineer "The farmers have received it (the project) very well. The farmers of the adjoining area are visiting this office and requesting installation of the system in their fields."

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