FINAL REPORT

On

PREPERATION OF ACTION PLAN FOR IMPROVEMENT OF IRRIGATION WATER USE EFFICIENCY

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1. INTRODUCTION

Improving performance of irrigation schemes in India has emerged as one of challenging issues for agricultural development. Irrigation efficiency is an indicator of effective water resources management. In order to improve irrigation efficiencies it is very important to keep track of where the water is going within the gross command area or boundaries of the system. Water balance or water accounting could help the planners to understand where the water within the command area of the scheme is actually going, which helps in correcting the management strategies. According to IWMI (2000), water balance provides information about all inflows and outflows within a defined boundary and also provides different water efficiencies such as conveyance efficiency, delivery efficiency, and application efficiency, while taking into account the multiple uses of water within the scheme.

Water is becoming increasingly scarce worldwide and more than one-third of the world population would face absolute water scarcity by the year 2025 (Seckler et al. 1998; Seckler et al. 1999; Rosegrant et al. 2002). The worst affected areas would be the semi-arid regions of Asia, the Middle-East and sub-Saharan Africa, all of which are already having a heavy concentration of population living below poverty line. The situation in India is also critical, where absolute water scarcity is already affecting a substantial part of the population and this proportion is increasing rapidly (Amarasinghe et al. 2005, 2007). Irrigation is the largest water consuming sector, accounting for more than 80 % of the total withdrawals.

India is amongst the largest irrigator countries in the world today. There is, however, increasing concern about some of the irrigation potential created not brought into the functional system, low operating efficiency, less crop productivity etc. With the increasing awareness for conservation of water, studies have been carried out to estimate the percentage of water losses in each part of the distribution system. In India CBIP Publication number 14 reported 17, 8 and 20 percent of water losses in main canal, distributaries and field or water course system respectively.

Irrigation has been a high priority area in economic development of India with more than 50% of all public expenditure on agriculture having been spent on irrigation alone. However the overall efficiency of canal irrigation system in India is only 30-35% (Sanmuganathan and Bolton, 1988). Low irrigation efficiency of these systems also contributes to poor utilization of the water resources in India. Therefore, the need of the hour is to increase the irrigation efficiency of existing projects and use saved water for irrigating new areas. At present average overall project efficiency of several canal irrigation projects in the rice growing areas in the world has been estimated to be 23% and that of nonpaddy crops to be 40 % (Walters and Boss, 1989). Most of the area in the country is irrigated by surface application methods such as check basin, border strip and furrow. The application efficiency of these methods has been found to be only 30 to 50 percent. This is due to the fact that these methods are not designed to match the stream size, soil type, slope etc. By adopting efficient irrigation practices, deep percolation losses can be reduced. By growing row crops, particularly cotton, maize, sugarcane, soyabean and sunflower under ridge and furrow irrigation system about 30-40 percent irrigation water can be saved compared to border irrigation. It is reported that on-farm irrigation efficiency for trickle irrigation can theoretically approach 90 to 95% (Bucks et al.1982). The problem of water scarcity in India is due to spatial variation in demand and supply of water. In India, a number of demand management strategies in the irrigation sector have been introduced with a view to increasing the water use efficiency (Vaidyanathan 1998; Dhawan 2002). However, the net impact of these strategies in increasing the water use efficiency so far has not been very impressive. Increasing water use efficiency is one of the five goals of the National Water Mission under national action plan on climate change.

The purpose of building and operating a canal system is to serve the farmlands, supply municipal and industrial needs, carry storm runoff to natural drainage channels, collect water from several independent sources into a single supply, convey water used for the generation of electrical power and supply water to fish and wildlife and for recreation. In order to serve the above purposes as efficiently and economically as practicable, canal operations should be tailored to meet the specific requirements of the systems.

Irrigation consumes maximum amount of water as compared to industrial uses and municipal supply. Improvement in irrigation efficiency will also help considerably in enhancing the availability of water for the drinking purpose. The possible end users of the proposed study may be the State Water Resources Departments, Command Area Development Authorities and departments responsible for urban, industrial and rural water supply including stakeholders in command areas.

This study is envisaged to review the prevailing water conveyance, application and its management practices and to formulate suitable action plan for improvement in irrigation efficiency of the existing irrigation projects in India. Efficiency status in drinking water supply and industrial uses will also be reviewed.

The outcome of the study will be helpful in preparation of action plan for the country to enhance the irrigation efficiency of the existing irrigation projects which is one of the priority activities identified in National Water Mission under national action plan on climate change. Also, it may be helpful in deciding the best possible combination of methods in a given situation to achieve high effectiveness of water use in optimal manner.

2. OBJECTIVES

The objectives of this study are to review the prevailing measures for improvement in irrigation efficiency of the existing irrigation projects in India considering the aspects of water conveyance, application methods and agricultural practices, and to suggest the best possible combination of measures/strategies to formulate region specific action plan for enhancing irrigation efficiency by 20 % in a time bound manner.

3. BRIEF REVIEW OF STATE-OF-THE-ART

Just 20% of the world's croplands are irrigated but they produce 40% of the global harvest which means that irrigation doubles the land productivity (FAO, 2003). About 50% of the total developed fresh water resources of Asia are devoted to growing rice (Barker et al., 2001). Increasing water scarcity threatens the sustainability of irrigated agriculture, and hence food security.

Postel (1993) estimated the worldwide irrigation efficiency, i.e. the amount of water used as evapotranspiration compared to the amount of water delivered to the field, to be about 37%. This estimate suggests that about 63% of the water delivered to the field is lost as runoff, drainage, or both. This means that in addition to 30% of water wasted in storage and conveyance, about 44% of the total water available at the source is lost as runoff and/or drainage. Wallace (2000) suggests that some of the water "lost" from an irrigated field may return to aquifers or streams from which it can be extracted again, provided the necessary infrastructure is available and the water quality has not deteriorated beyond acceptable limits.

Kigalu et al. (2008) studied the effects of drip irrigation on the yield and crop water productivity responses of four tea (Camellia sinensis (L.) O. Kuntze) clones in four consecutive years (2003/2004–2006/2007), in a large (9 ha) field experiment comprising of six drip irrigation treatments (labelled: I1–I6) and four clones (TRFCA PC81, AHP S15/10, BBK35 and BBT207) planted at a spacing of 1.20 m × 0.60 m at Kibena Tea Limited (KTL), Njombe in the Southern Tanzania in a situation of limited water availability. Results showed that drip irrigation of tea not only increased yields but also gave water saving benefits of up to 50% from application of 50% less water to remove the cumulative soil water deficit and with labour saving of 85% for irrigation.

Malhotra et al. (1984a) described a methodology for monitoring the performance of large-scale irrigation system using a case study of a warabandi system of northwest India. The study area covered a distributory with a command area of 22389 ha. An important contribution of their study is the use of "wetted area" as an indicator of water supply for a farmer's field in a water-deficient system. They defined the net wetted area (NWA) as the area of farmer's land that is wetted at least once in an irrigation season; the total wetted area (TWA) is the NWA multiplied by the number of irrigations that the area receives. The area of every individual farmer that can be irrigated is measured and recorded. This area is called the cultivable command area (CCA). In the case study of warabandi system, the predicted outputs are: (1) NWA is equal to one-third of CCA; and (2) TWA is equal to 133 % of CCA. By measuring the actual outputs of NWA and TWA it is possible to determine if the results of the warabandi system are within an acceptable range of error. They also defined the allocative efficiency as the coefficient of determination between the wetted area after a watering on each farm (NWA), and the farm area (CCA). This will be one when there is perfect equity, in the sense that every farmer receives a share proportional to the size of holding. The conclusion was that allocative effectiveness was 80% at the distributory level and 90% at the watercourse level.

Seckler et al. (1988) in a continuation of the analysis of the Malhotra et al. (1984) study, develop a performance index for measuring the performance of irrigation systems. They concluded that the coefficient of determination previously proposed is not a valid index of performance and suggested a new index defined as the relationship between the concepts of Management by Results (MBR). In MBR, the results (R) are defined as the relationship between the predicted outputs (P_o) of the system and the actual results (Ao) obtained from operation of the system. The results are expressed as a ratio, $R = A_O/P_O$. If the system is performing perfectly, Ao = Po and R = 1.0. The index is applied to a sample of 39 farms on a watercourse under the *warabandi* system of irrigation management in India. It is found that while the farmers in fact irrigated almost exactly the total amount of irrigated area as designed, inter-farm variations were considerable. The index shows that the degree of error of managerial effectiveness of irrigation on this watercourse is 20 percent. Therefore it is concluded that the system is performing at 80 percent effectiveness.

Another field study of the performance of Warabandi in Punjab (India) is described by Goldsmith & Makin (1988). The field measurement was tested for 24 days during February and March 1988 in Ferozpur District of south-west Punjab. The study area includes the commands of Mudki and Golewala Distributaries. Mudki Distributory has a command area of 30894 ha and serves 2 minor canals and 59 watercourses. Golewala Distributory has a command of 28727 ha and supplies 3 minors and 59 watercourses. Both Distributaries and majority of water courses have been lined over the past eight years. Measurements were made of flows, losses and water levels in order to give estimates of equity of supply, adequacy of supply, seepage and conveyance losses at both distributory and watercourse level. The flow and seepage was measured using the portable current meter and Ponding test respectively. A normalized equity called IQR (Abernethy 1986) was calculated for each distributory and compared with similar schemes. Patterns of supply ratio (actual/design flows) for each watercourse along the distributory were identified and variations explained in terms of difference between "designed" and "as-built" off take structures. The measured IQR was 1.35 for Golewala Distributory is very good and conveyance efficiency was 53 % at present, but this may fall to 42% without improved maintenance of linings.

In several irrigated regions, shortage of water and inadequate availability of funds maintaining irrigation works have focused attention on the potential for water charges to generate financial resources and reduce demand for water through volume-based charges (Perry, 2001).

Various types of irrigation water supply system in different regions in India. Some of these are listed here.

Supply Based: the Warabandi system is practiced in North West India (Punjab, Haryana and parts of Rajasthan and Uttar Pradesh).
Demand Based: the Shejpali system is practiced in Western and Central India (Gujarat, Maharashtra and part of Madhya Pradesh)
The localization system is practiced in South India (Andhra Pradesh, Karnataka and Tamil Nadu). **Field-to-field system** is applied in the deltas (Southern and Eastern delta areas: Godavari, Krishna and Cauvery).

A field study of water losses and estimation of irrigation efficiency was carried out on Dabathua distributor in Salwa command area by Sharma (1982). The study shows that in unlined water course the rate of conveyance loss was more than twice than that of the main, distributaries and minor canals. Using inflow outflow method, it was estimated at 1.16×10^{-5} m^3/m of channel (10.70 $m^3/10^6 m^2$) whereas seepage loss rate measured using ponding method was found in the order of about 4.4 $m^3/10^6 m^2$. This shows that conveyance losses are approximately two time the seepage losses. Overall efficiency below outlet has been estimated to be 40 percent. Total seepage losses in the Ganga canal were found to be about 44%, (Choudhury, 1982). These losses include 15% in main canal and branches, 7% in distributaries and 22 % in water courses. From the above results, it may be concluded that the watercourses are the major source of water loss.

Detailed studies on water use efficiency for 30 irrigation project in India were carried out by various WALMIs/ IMTIs for CWC (CWC, 2010), the findings of these studies will be appropriately utilised in this study. The summary of the outcome of these studies is presented in Table 1. MoWR has also implemented farmers Participatory Action Program on Pilot basis under which related methods and techniques, agricultural practices has been demonstrated in farmer field. Considerable improvement in Water Use efficiency has been reported in this program.

Therefore, there exists considerable scope for improvement in unlined water courses (Sharma, 1982).

Percolation losses from earthen irrigation channels depends on intrinsic permeability of the strata through which the channel passes and vary from 30 to 50 percent of discharge available at the head of an irrigation system. Ministry of Irrigation and Power, New Delhi (1972) reports that the commonly accepted figures for transit losses in the alluvial plains of north India are 17 % for main canal and branches 8 % for distributaries and 20 % for water course, which gives a total loss of 45 % of the water entering the canal head. Then there are further losses in the field itself, and these have been estimated at 30 % of the supply reaching the field or 17% of the head discharge. Observation on Punjab canal and Ganga canal shows that out of 100 % passing at head only 55 % and 56% reaches the field.

A study to improve the efficiency of distribution system of Musafirkhana pilot project was carried out in Sharda Sahayak Command area on farm development work. In this study significant improvement in the water saving from water courses could be achieved through suitable layout and maintenance of water course (Belliah, 1981).

Among advanced micro-irrigation (MI) techniques, drip and sprinklers are gaining special attention. Drip irrigation (DIM) and sprinkler irrigation (SIM) methods have distinct characteristics in parameters such as flow rate, pressure requirement, wetted area and mobility (Kulkarni 2005), but they have the potential of significantly increasing water use efficiency. DIM has little or no water losses through conveyance (INCID 1994; Narayanamoorthy 1996, 1997; Dhawan 2002), and the on-farm irrigation efficiency of a properly designed and managed drip irrigation system can be as high as 90 %, compared with 35 to 40 % efficiency in surface method of irrigation (INCID 1994). However, SIM has relatively less water saving (up to 70 % efficiency), since it supplies water over the entire field of the crop (INCID 1998; Kulkarni 2005). Besides higher water use efficiency, MI has other economic and social benefits too. Research station experiments show MI increases productivity by 20 to 90 % for different crops (INCID 1994, 1998); reduces weeds, soil erosion; cost of cultivation, especially in labour-intensive operations; energy use (electricity) for operating irrigation wells due to reduced water consumption (Narayanamoorthy 1996 and 2001). Summary report of water-use efficiency studies for 30 irrigation projects in India is given in table 1.

Agarwal and Dixit (1972) conducted a comparative study for onion, radish and okra at Hissar on drip and furrow irrigation. They reported 25 percent water saving in drip irrigation plot compared to furrow irrigated plot. Yield and quality of crops were observed superior in drip treatment.

There is no precise study reported in literature which evaluates the measure for improvement of water use efficiency of irrigation project in India. In this study it is proposed to review the suitability of different measures pertaining to increase in irrigation efficiency. It includes the appropriate measures to minimize water loss from water conveyance, application method, and its management.

Table 1. Summary of reported water-use efficiency in various projects in India (CWC, 2010)

Sl. No.	Name of Project	Dam/Reservoir efficiency	System Efficiency (%)
Andhra Pradesh			
1.	Bhairavanithippa Project WALMI, HBD	Reservoir filling efficiency gross storage-53.47 MCM; Live storage-51.59 MCM; Actual storage = 27 MCM during Nov 2002	Conveyance efficiency of RMC: 86.51% On farm application efficiency: 66.87% Overall project efficiency: 57.85%

2.	Gajuladinne (Sanjeevaiah Project), WALMI, HBD	Reservoir filling efficiency gross storage-148.68 MCM;Live storage-121.21 MCM; Actual storage = 26.22 MCM during Oct 2004	Conveyance efficiency of RMC: 56.76%. On farm application efficiency: 45.37% Overall project efficiency: 25.75%
3.	Gandipalem Project, WALMI, HBD	Reservoir filling efficiency gross storage-53.24 MCM; Live storage-45.88 MCM;Actual storage = 3.68 MCM during Oct 2004	Conveyance efficiency of RMC: 85.36%. LMC: 80.36% Distributory D3 of RMC=86.44% On farm application efficiency: 38.40% Overall efficiency: 28.03%
4.	Godavari Delta System (Sir Arthur Cotton Barrage) WALMI, HBD	Reservoir filling efficiency gross storage-83 MCM; Live storage-60.06 MCM; Actual storage = 3.68 MCM during April 2005	Conveyance efficiency of RMC: 83.21% On farm application efficiency: 54.15% Overall project efficiency: 45.05%
5.	Kurnool-Cuddapah Canal System WALMI, HBD	Diversion scheme	Conveyance efficiency of RMC: 56.76%. On farm application efficiency: 45.37% Overall project efficiency: 25.75%
6.	Kaddam Project WALMI, HBD	Reservoir filling efficiency gross storage-215.3 MCM; Live storage-136.55 MCM ; Actual storage = 198.67 MCM during Sept 2005	Conveyance efficiency of project: 51.25% On farm application efficiency: 36.13 % Overall project efficiency: 18.52%
7.	Koil Sagar Project WALMI, HBD	Reservoir filling efficiency gross storage-64.46 MCM; Live storage-59.89 MCM; Actual storage = 1.19 MCM during Sept 2005	Conveyance efficiency of project: 82.62%. On farm application efficiency: 75% Overall project efficiency: 61.96%
8.	Krishna Delta System(Prakasam Barrage)	Reservoir filling efficiency=100%	Conveyance efficiency of main canal: 88 to 99.4% (K.E.Delta) 92.24 to 99.15%(K.W.Delta)

			On farm application efficiency: Not observed but evaluated 35 to 45.03%
9.	Nagarjuna Sagar Project, WALMI, HBD	Reservoir filling efficiency gross storage-408.24 MCM; Live storage-202.47 MCM; Actual storage = 307.52 MCM during Oct 2004	Conveyance efficiency of canal: 55.96%. On farm application efficiency: 38.93% Overall efficiency: 21.80%
10.	Narayanapuram Project	Diversion scheme	Conveyance efficiency of RMC: 46.57%. On farm application efficiency: 31.18% Overall project efficiency: 14.52%
11.	Nizamsagar Project WALMI, HBD	Reservoir filling efficiency gross storage-504 MCM; Live storage-504 MCM; Actual storage = 382.8 MCM during Nov 2005	Conveyance efficiency main canal: 87% On farm application efficiency: 45.32% Overall project efficiency: 39.43%
12.	Srisailam Project(Neelam Sanjeeva Reddy Sagar) , WALMI, HBD	Reservoir filling efficiency gross storage-308.06 MCM; Live storage-253.05 MCM; Actual storage = 263.16 MCM during Oct 2005	Conveyance efficiency of canal: 50%. On farm application efficiency: 33.94% Overall efficiency: 17%
13.	Rajolibandra Diversion Scheme (RDS) WALMI, HBD	Diversion Scheme	Conveyance efficiency main canal: 82.83% On farm application efficiency: 51.51% Overall project efficiency: 42.65%
14.	Somasila Project	Reservoir filling efficiency gross storage-2221 MCM; Live storage-1994 MCM; Actual storage = 1438.97 MCM during Nov 2005	Conveyance efficiency of canal system: 67.86%. On farm application efficiency: 31.84% Overall project efficiency: 18%

15.	Sri Ram Sagar Project , WALMI, HBD	Reservoir filling efficiency gross storage-3171 MCM; Live storage-2322 MCM; Actual storage = 3055.8 MCM during Sept 2005	Conveyance efficiency of Kakatiya canal above L.M.D : 97.93 % Below L.M.D=90.77% On farm application efficiency: 57.28% Overall efficiency: 44.66%
16.	Tungabhadra High Level Canal (TBL-HLC)	Reservoir filling efficiency gross storage-146.4 MCM; Live storage-135.07 MCM ; Actual storage = 68.75 MCM during Sept 2004	Conveyance efficiency of project: **80.8%** On farm application efficiency: 75.8 % Overall project efficiency: 58.32%
17.	Tungabhadra Low Level Canal (TBL-LLC)	Reservoir filling efficiency gross storage-3157.497 MCM; Live storage-3157.497 MCM; Actual storage = 3157.497 MCM during Aug 2004	Conveyance efficiency of project=72.18**%.** On farm application efficiency: 44.80% Overall project efficiency: 32.33%
18.	Upper Mandir Project WALMI,HBD	Reservoir filling efficiency gross storage-62.30 MCM; Live storage-61.43 MCM; Actual storage = 2.57 MCM during Jun 2003	Conveyance efficiency of main canal: **90.50%)** On farm application efficiency: not found Overall project efficiency: not found
19.	Vamsadhra project (Stage-1) WALMI, SBD	Reservoir filling efficiency gross storage-17.33 MCM; Live storage- 17.33 MCM; Actual storage = 17.33 MCM	Conveyance efficiency of project: **90.50%** On farm application efficiency: 58.47 % Overall efficiency: 52.91%
20.	Yeleru Project WALMI, HBD	Reservoir filling efficiency gross storage-682.85 MCM; Live storage-506.30 MCM; Actual storage = 316.58 MCM during Dec 2004	Conveyance efficiency of project=50**%.** On farm application efficiency: 28.42% Overall project efficiency: 14.21%

Haryana			
21.	Augmentation Canal Project, Kurukshtra	No diversion provision	Conveyance efficiency of main canal: **79%** On farm application efficiency: 72%
22.	Naggal Lift irrigation Project , Haryana	No diversion provision	Conveyance efficiency of main canal: 47.82**%** On farm application efficiency: 27% Overall efficiency:13%
Punjab			
23.	Dholbaha Dam Project IPRI,Amritsar	Reservoir filling efficiency:61.50%	Conveyance efficiency of canal system: **74.27%** On farm application efficiency: 71 % Overall project efficiency: 52.73%
24.	Ranjit Sagar Dam	Reservoir filling efficiency 57.35%	Conveyance efficiency of canal system=: 97.57%, 93.07%, 77.17 of UBDC main, MBU, MBL respectively. Water supply adequacy index= 9.89% (for rabi crop) and 12.565(Kharif crop)
Uttar Pradesh			
25.	Ahraura Dam Irrigation project,WALMI,LKO	Reservoir filling efficiency 91.3%	Conveyance efficiency of main canal: 42 to 80**%** Overall efficiency: 49.2%
26.	East Baigul Reservoir Project	Reservoir filling efficiency 84.77%	Conveyance efficiency of UBC Feeder System: **64%** Bara canal System: **63%** Overall efficiency: U.B.C. system**:** **48%** in Kharif & **41.6%** in Rabi Bara Canal System: **47.3%** in Kharif & **41%** in Rabi.
27.	Matatila Dam Project,	Reservoir filling efficiency gross 67.36%	Conveyance efficiency main canal. Betwa Canal System: **68.2%**

	WALMI,LKO		Gursarai Canal System: **67.8%** On farm application efficiency: 80% Overall project efficiency: 54.6 to 54.2%
28.	Naugarh Dam irrigation project WALMI, LKO	Reservoir filling efficiency Gross: 81.4%	Conveyance efficiency of canal system: 70.7**%.** Overall project efficiency: 49.5%
29.	Pili Dam project WALMI, LKO	Reservoir filling efficiency: 47.53%	Conveyance efficiency of main canal system: **58%.** Overall efficiency: 37.7 to 43.5 Water supply adequacy index: 0.54 to 0.70
30.	Walmiki Sarovar project, WALMI, LKO	Reservoir filling efficiency: 61.15%	Conveyance efficiency of main canal system: **43%.** On farm application efficiency:62% Overall efficiency: 37.7 to 43.5

Source: Summary report on Water Use Efficiency (WUE) Studies for 30 Irrigation Projects. Performance overview and management improvement Organisation (POMIO). Central water Commission, Government of India (2010)

4. APPROACH

Intensive review of relevant literature on enhancement of irrigation water use efficiency in India and abroad is carried out. Based on available literature on water conveyance, application methods, on-farm management of irrigation efficiency in India and abroad, practicable techniques and measures are identified. One-day brain storming session at Roorkee was organised and comprehensively debated the issues and techniques including output of various studies carried out in various command areas in India. Depending on soil type, climate, cropping pattern and prevailing experience, the suitable measures for enhancing irrigation water use efficiency in different regions were categorised. Practicable combinations of set of measures have been suggested to improve irrigation water use efficiency in existing projects.

5. RECOMMENDATIONS

The available literature and from the past experience, the following actions / combination of measures may be required for enhancing the irrigation efficiency in the existing irrigation projects.

5.1 SHORT TERM MEASURES:-

5.1.1 Management options:-

5.1.1.1 Regulated Deficit Irrigation (RDI)

Regulated deficit irrigation is an optimization strategy in which irrigation is applied during drought-sensitive growth stages of a crop. Outside these periods, irrigation is limited or even unnecessary if rainfall provides a minimum supply of water. Water restriction is limited to drought-tolerant phenological stages, often the vegetative stages and the late ripening period. Total irrigation application is therefore not proportional to irrigation requirements throughout the crop cycle.

General techniques

i. Measure fruit and shoot growth to determine the regulated deficit irrigation period for fruit species/varieties in an orchard.

ii. Excavate one side of a tree to determine root distribution, including information on root zone width and depth.

iii. Determine the wetting pattern of the irrigation system and estimate wetted root zone.

iv. Develop a season irrigation plan for run time and interval based on soil type, wetting pattern and average pan evaporation.

v. Install soil water sensors (preferred measure is soil water tension using gypsum blocks at 30 cm and bottom of root zone in shallow soil, at 30 cm, 60 cm and bottom of root zone in deep soil).

During regulated deficit irrigation period

i. Measure and record soil water tension and irrigate when the entire root zone dries out to a minimum of 200 kPa.

ii. Irrigate to wet the top 30 cm of the root zone.

iii. Measure and record soil water 6 to 12 hours after irrigation and, if necessary, adjust the amount applied in previous irrigations to wet soil to 30 cm depth.
iv. Irrigate when the wetted root zone soil at 30 cm depth dries out to 200 kPa.
v. Measure pan evaporation between irrigations, and irrigate in future years based on this cumulative evaporation.

During rapid fruit growth

i. Irrigate to wet at least the top 60 cm of root zone.
ii. Measure and record soil suction 6 to 12 hours after irrigation and, if the soil is drier than 30 kPa (sandy soil) or 50 kPa (clay soil) at 60 cm, apply more irrigation.
iii. Irrigate when the wetted root zone soil water tension at 30 cm depth dries out to 30 or 50 kPa.
iv. Measure pan evaporation between irrigations, and irrigate in future years based on this cumulative evaporation.

Single irrigation, compared to the conventional four or five irrigations, has been practised in northern China on winter wheat on a relatively large scale since 1991. In a field study, irrigation was reduced from normally four times (I_4, 4×75 mm) to one (I_1, 75mm at the end of the second internode elongation) in an area with an annual rainfall of about 600 mm. A control without irrigation (I0) was also included. Late sowing and early soil drying at seedling stage resulted in a relatively deep root system. Leaf area index, the size of upper leaves and the length of base internodes were also significantly reduced under I1, but kernel number per panicle was not reduced, suggesting that the development of inflorescence was not disrupted. During the active grain filling stage, it was found that leaf water potential under I1 was maintained similar to that of I4, while daytime stomatal conductance was substantially reduced. Leaf temperature was increased, indicating an inhibited leaf transpiration. Early senescence was induced in I1 and I0 crops and resulted in a substantially lower kernel weight. Although the grain yield of I1 was reduced by about 15% from I4, the water-use efficiency (WUE) for total water consumption was increased by 24±30%. Single irrigation can potentially make wheat cropping sustainable in this area in terms of water usage and prevent further depletion of the underground resource. Explanations for the small or zero reduction in yield are: (1) the encouraging development of a deep root system that enabled the plants to use more water at depth (below 1 m), which is recharged annually by the relatively high summer rainfall. (2) A large portion of root system in the drying soil and its induced shoot physiological changes, that is, reduced leaf expansion and stomatal conductance, which helped the plants to establish a better canopy structure with a much reduced water consumption.

Implementing regulated deficit irrigation

For regulated deficit irrigation to be effective, a number of prerequisites must be met for either fruit trees or grapevines. These are as follows:

i. For fruit trees measure shoot and fruit growth because understanding the changes in fruit and shoot growth for different varieties is critical for timing regulated deficit irrigation. Water stress should be applied only during the vegetative growth period when fruit is growing slowly. Water stress must be avoided or minimised (if water is limited) during rapid fruit growth. The stages of fruit growth for a given variety can be easily determined by tagging several fruit and shoots and weekly measuring their circumference and length with a tape measure. Fruit circumference is converted to volume [volume = 0.02 x $(\text{circumference})^3$] to give a true indication of fruit weight. This technique is very simple and the measurements can be quite useful to adjust irrigations, especially if shoot growth continues despite high soil water deficits.

ii. Assess root distribution to calculate the potential store of available moisture in the soil. The best method to determine root distribution is to dig a pit next to an orchard tree and estimate the amount of roots in 20 cm depth increments until the bottom of the root zone (80% of roots). Root depth is important to determine the volume of water in the root zone when the profile is wet from rainfall, and where to site soil moisture sensors.

iii. Estimate soil water holding capacity in the root zone. In particular, determine a representative value of readily-available water (RAW) for each sector in the irrigated orchard or vineyard, i.e. shallow *versus* deep profiles and coarse sand *versus* finer textured soils. As a general rule, RAW (as a percentage of soil volume) for major types of horticultural soils are as follows: coarse 3%; fine sandy loam, 6%; loam, 8% clay-loam, 6 to 8%; and finer textured (heavy) clay soils, 6%.

iv. Identify wetting patterns to determine the volume of the wetted root zone. This can be estimated from the root distribution and the wetted volume of soil. To determine the wetting volume it is necessary to observe the wetted surface area and depth following an irrigation event.

v. Dig a hole to see wetting at depth. The wetted root zone is then estimated from the volume of roots that are wet following irrigation. The calculation in the following irrigation plan assumes that the wetting pattern is a continuous strip of soil with a wetting depth of 30 cm. This wetted strip pattern will occur with closely spaced micro jets or drippers where the wetting pattern overlaps. For other irrigation systems where the wetting patterns are separate, the wetted root zone is calculated assuming the shape.

Irrigation systems

No specialised irrigation equipment or system modification is needed for regulated deficit irrigation beyond what would normally be installed for closely managed irrigation. This includes irrigation supply network, root zone soil moisture sensing and environmental monitoring (weather station or evaporative pan).

A snapshot of regulated deficit irrigation and partial rootzone drying Regulated deficit irrigation and partial rootzone drying are designed to limit vegetative vigour and improve water use efficiency in perennial crop plants such as grapevines and fruit trees. This shift in crop management, compared with traditional irrigation methods which use more water, is a feature common to both regulated deficit irrigation and partial rootzone drying. These two methods of irrigation do, however, differ fundamentally in two key respects. With regulated deficit irrigation water application is manipulated over time whereas, with partial rootzone drying irrigation, water is manipulated over space.

Although the way the two systems work differs significantly, the ultimate outcomes of regulated deficit irrigation and partial rootzone drying are similar in that they limit vegetative growth and enhance water use efficiency for crop production. With both irrigation methods, canopy growth is constrained in favour of crop development. A smaller canopy allows more light to enter the tree or vine and this enhances initiation and differentiation of fruit buds. This means that water use efficiency for crop production is improved while cropping potential for the next season is not necessarily affected.

Successful regulated deficit irrigation requires the following:

Regulated deficit irrigation is the practice of using irrigation to maintain plant water status within prescribed limits of deficit with respect to maximum water potential for a prescribed part or parts of the seasonal cycle of plant development. The aim in doing this is to control reproductive growth and development, vegetative growth and/or improve water use efficiency.

It follows that the re-wetting frequency under regulated deficit irrigation should be determined by detection or prediction of a decrease in plant water potential below a prescribed limit. Ideally this should be measured in terms of plant water potential but in practice, for convenience and cost saving, this may be inferred from soil moisture depletion or estimates of plant water use based on evaporative conditions or measurement of sap flow.

i. Entire irrigation system permits frequent and measured applications of water at critical times during the regulated deficit irrigation phase.
ii. System has enough capacity to restore root zone moisture quickly over the entire orchard or vineyard following release from deficit.

A secure water supply is crucial and must be available on demand to meet the widely varying irrigation requirements of orchards and vineyards on a deficit regime. Frequent deficit irrigations will be needed during regulated deficit irrigation, while substantial and sustained irrigation is needed during subsequent restoration to full irrigation. Application rates after regulated deficit irrigation are likely be 100 to 150% of potential crop evapotranspiration to fully restore root zone moisture in time for rapid fruit growth.

Soil attributes

Successfully implementing regulated deficit irrigation hinges on certain soil attributes, including a limited store of root zone soil water, readily permeable surface layers that make irrigation water easier to absorb, and a well defined soil type and depth that allows an irrigation schedule to be calculated.

At budburst in most temperate-climate orchards and vineyards, soil profiles are usually fully charged after rain in winter or spring. To impose some water stress (as required by regulated deficit irrigation), the root zone must first be de-watered. Canopy transpiration and surface evaporation contribute to that process and, even though soil water content decreases to a point where canopy transpiration cannot match atmospheric demand, irrigation is withheld until the soil is dry enough to induce water stress in the fruit trees or grapevines.

The time required for de-watering will depend on evaporative conditions, root zone depth, the extent of lateral root distribution, soil water holding capacity, and further rainfall. For successful regulated deficit irrigation, root zone depth needs to be less than about 1 metre, and rainfall during the regulated deficit irrigation period at an absolute minimum (ideally nil).Soil type is important in determining what irrigation system should be installed for efficient regulated deficit irrigation. For deep sandy soils and the sandy loam, regulated deficit irrigation would most likely use a pressurised system of closely spaced (75 cm) drippers (vineyards) or micro jets (tree crops). For successful regulated deficit irrigation, enough soil must be wet up to enable rapid relief of water stress for maximum fruit growth or sugar accumulation, or both, once full irrigation is restored. In drip-irrigated tree crops a second drip line is often installed. Low-level sprinklers would also be suitable, as would overhead sprinklers on properties where these systems are installed.

5.1.1.2 Partial Root Zone Drying (PRD)

Partial rootzone drying is the practice of using irrigation to alternately wet and dry (at least) two spatially prescribed parts of the plant root system to simultaneously maintain plant water status at maximum water potential and control vegetative growth for prescribed parts of the seasonal cycle of plant development. The reason for doing this is to control vegetative growth or improve water use efficiency or both while maintaining reproductive growth and development.

Controlled alternate partial root-zone irrigation (CAPRI), also called partial root-zone drying (PRD) in other literature, is a new irrigation technique and may improve the water use efficiency of crop production without significant yield reduction.

It follows that the re-wetting frequency under partial rootzone drying should be determined by detection or prediction of completion in extraction of soil water from the drying side. In practice this can be identified from soil moisture depletion or estimates of plant water use based on evaporative conditions or measurement of sap flow.

Partial root zone drying is the practice of using irrigation to alternately wet and dry (at least) two spatially prescribed parts of the plant root system to simultaneously maintain plant water status at maximum water potential and control vegetative growth for prescribed parts of the seasonal cycle of plant development. The reason for doing this is to control vegetative growth or improve water use efficiency or both while maintaining reproductive growth and development.

Partial root zone irrigation was tested for its soil water distribution, water uptake, and water use efficiency (WUE) on pear trees in a commercial orchard (Goulburn Valley, central Victoria, Australia) in 1998–1999. Irrigation was applied through in three ways: conventional flood irrigation (CFI), fixed partial root zone irrigation (FPI), and alternate partial root zone irrigation (API). CFI means that both sides of the root zone were flood-irrigated. Under FPI, flood irrigation was fixed to one side of the root zone, and the other side was kept dry. The API means that one of the two sides of the root zone was alternately flood-irrigated during consecutive watering. A total of four irrigations were applied for all treatments during the pear fruit-growing season.

Results showed that water use peaked after each irrigation and rainfall. Maximum water use of the pear orchard exceeded 7.0 mm/day in mid-summer and thereafter it declined to around 3.5 mm/day during mid-autumn. Irrigation on the FPI and API was reduced by 52 and 23% and water use by 28 and 12%, respectively, compared to the CFI in the 0–110 cm soil layer. The water uptake in the irrigated wet sides of API and FPI was more than the same side in the CFI, suggesting a compensatory effect in the wet part of the root zone. When less irrigation was introduced in the FPI, the fruit number, yield per tree, and the total yield in unit area were not affected. As a result, WUE of the pear trees was substantially improved in the FPI treatment under a shallow groundwater table condition. We conclude that the fixed partial root zone drying technique could substantially save water without much reduction of fruit yield. © 2002 Published by Elsevier Science B. V.

By practising single ridge furrow irrigation method, one can easily adopt CAPRI /PRD technique with improved WUE.

5.1.2 Supplemental Irrigation for Kharif crops (Irrigating to supplement precipitation so as to avoid crop failure).

Supplemental irrigation (SI) can be defined as the addition of small amounts of water to essentially rainfed crops during times when rainfall fails to provide sufficient moisture for normal plant growth, in order to improve and stabilize yields. SI in areas with limited water resources is based on the following three premises:

i. Water is applied to a rainfed crop which would normally produce some yield without irrigation.

ii. Since precipitation is the principal source of moisture for rainfed crops, SI is only applied when precipitation fails to provide essential moisture for improved and stabilized production.

iii. The amount and timing of SI are not scheduled to provide moisture-stress-free conditions throughout the growing season, but to ensure that the minimum amount of water required for optimal (not maximum) yield is available during the critical stages of crop growth. Supplemental irrigation is the opposite of full or conventional irrigation (FI). In the latter, the principal source of moisture is fully controlled irrigation water, and highly variable limited precipitation is only supplementary. Water for supplemental irrigation comes mainly from surface sources, but shallow groundwater aquifers increasingly are being used. Among non-conventional water resources that have potential for the future, such as treated sewage water-harvesting is also important.

iv. In-situ moisture conservation (Enhanced precipitation capture): In situ retention of rain water can help a lot in recharging the ground water. Studies have indicated that raising peripheral bunds to a height of 18-20 cm around the fields could store nearly 90% of total rainwater in-situ for improved rice production and reduce the need of irrigation water.

5.1.3 Paradigm shift from existing supply management to demand management.

The majority of canal systems in India are operated in a manner which is referred to as conventional operation. A conventional operation consists of a scheduled delivery, an upstream operational concept and a constant downstream depth operational method.

Conventional operation evolved as a practical method of satisfying irrigation needs within traditional canal system limitations. By using delivery schedules, it essentially combines demand-based needs with supply-based operation. The purpose of conventionally operated canals is demand-oriented, since the primary goal is to satisfy the needs of the water users. The downstream demand for water is assessed in advance so as to schedule the supply of water entering the canal through the headwork. Although the headwork flow is based on this schedule of anticipated demand, the actual operation of the canal is based on the supply.

5.1.4 Suitable water application methods and real time soil moisture measurement.

i. Furrow Irrigated Raised Beds: To overcome the problem of aeration in wheat due to excessive irrigation of heavy rains in less permeable fine textured soils and to improve the efficiency of applied water, it has been recommended to grow wheat on raised beds. The practice of bed planting in timely sown wheat under medium to heavy textured soils, having good soil moisture has shown a great promise to realize this objective with comparable to better (3-4%) wheat yield and facilitating efficient use of water. On an equal area basis, depth of irrigation required in bed planted wheat is 5.0 cm as compared to 7.5 cm under conventional (flat) sown wheat. In heavy textured soils bed transplanting of paddy has also been recommended. Bed transplanting of paddy helps in saving of 25 per cent of irrigation water without any loss of crop yield. Raised bed planting is also convenient for crops like sunflower, chilli, potato and chickpea etc. for economic use of irrigation water.

ii. Furrow Irrigation method in wide row crops: Furrow or alternate irrigation method in wide spaced crops like cotton, maize, sunflower Sugar-cane, potato etc. is more economical than the conventional flood irrigation method. In furrow irrigation water loss can be reduced because the wetted area is reduced. Water lost due to evaporation from soil surface and due to percolation is reduced to much extent. This technology helps in saving of 25-40 per cent of irrigation water over flat irrigation, without any loss of crop yield. The technique is very beneficial in fine textured soils where water stagnation in the root zone causes aeration stress.

iii. Micro Irrigation: The conventional methods of water conveyance and irrigation, being highly inefficient has led not only to wastage of water but also to several ecological problems like waterlogging, salinization and soil degradation. It has been recognized that use of modern irrigation methods viz. drip and sprinkler irrigation is the only alternative for efficient use of surface as well as ground water resources. The water use efficiency in these systems is much higher than the flood method of irrigation. The scheme on Micro irrigation which aims at increasing the area under efficient methods of irrigation viz. drip and sprinkler irrigation has been launched. This is a centrally sponsored scheme under which out of the total cost of the system 40% will be borne by the Central Government, 10% will be borne by the state Govt. and the remaining 50% will be borne by the beneficiary.

Soil Moisture Measurement

Scheduling of irrigation with proper measurement of soil moisture content to irrigate, when actually the crop needs water, appears to be one of the effective strategies for enhancement of water use efficiency. Few tensiometers are usually installed at certain selected representative locations over a region to measure soil suction precisely for determination of irrigation intervals. In a field study carried out by PAU, Ludhiana indicated that tensiometer is an effective device which works on the principle of soil-water tension and guides the farmer as and when to irrigate their paddy fields. Further, study revealed that the irrigation scheduling using Tensiometer saves 11 to 31% of irrigation water as compared to the present practices without having any adverse effect on crop yield. Hira et al. (2007) and Sidhu et al. (2008) reported that irrigation scheduling using Tensiometer can save 20% and 25-30% of irrigation water, respectively, without affecting Paddy yield.

5.1.5 Installation of appropriate water measuring devices in the conveyance system for volumetric measurement.

For the irrigator to apply the specified amount of water at each irrigation, there must have some method of water measurement. Flow measurement devices can be installed in open ditches and in pipelines. Some examples are Parshall flumes, Cutthroat flumes, Replogle flumes, weirs, orifice plates, and flow meters. In addition to telling farmers how much water has been pumped, meters are also useful in determining the efficiency of a pumping plant and detecting potential well and pump problems before they become a serious problem. Installation of flow measuring devices will not in itself conserve water. These devices must be maintained and used by the irrigator to control the amount of water applied. They will be most effective when used in conjunction with an irrigation scheduling program.

5.1.6 Night Irrigation.

Farmer's pluses

Exceptionally, the supply of irrigation water at night is welcomed or valued by farmers. There are four general reasons.

i. Where it is very hot, farmers sometimes prefers to irrigate at night because the worst time for a turn was midday due to heat. The main reason for night preference was personal comfort. In general, the warmer the climate, the more acceptable it is to be up and active at night.
ii. Where farmers are part-time, and have work during the day, they may prefer water supplied in the evening or at night when they can be present to apply to it.
iii. Talented farmers, as on the Lower Bhavani Project in Tamil Nadu, sometimes say they prefer to irrigate at night because the water supply is more adequate and reliable, not being extracted by the same degree by upstream farmers. However this preference is dictated by circumstance, and no doubts they would prefer a similarly adequate and reliable supply by day.
iv. Irrigation at night can be valued socially.

Farmer's minuses

It is however more common to farmer to dislike night irrigation at night. The reasons are:

i. Loss of sleep. This includes tiredness and inconvenience and perhaps financial and social costs of needing to sleep during the day, besides the disruption of normal habits of sleep.
ii. Discomfort. Night can cold be especially in winter and spring (Rabi) seasons and it is harder at night to keep clean and move about in sticky soils and mud.
iii. Danger and fear. Snakes and scorpions are feared, though a case of snake or scorpions bite at night is rare. Ghost and spirits are also feared. If water is poached at night,

physical danger is often involved. Law and order conditions can also deter irrigation at night; dacoits can be a risk and farmer near Coimbatore in South India also fear robbery and harm to their wives and families left in their houses. At night, physical harm is also more likely through accidents such as getting cut on sugarcane fronds, getting pricked or scratched by thorns and slipping, falling and stubbing toes.

iv. Cost. It usually costs farmers more to irrigate at night. Especially on sloping lands with difficulty soils, and with standing crops, irrigation at night requires additional cost. Breaches in supply channels are harder to see and harder to mend, and sometime an extra person is needed to hold at night. Wages are higher at night, often between half as much and double that for work during day and lighting is another cost.

v. Inefficient application. In darkness it is harder to judge the correct applications of water, to see whether all of plots have been irrigated or to notice and mend a breach. Inefficiency and losses are especially marked if irrigation is unsupervised or labour inadequate.

5.1.7 Control on cropping pattern.

Among the management factors for more productive farming systems are the use of suitable crop varieties, improved crop rotation, sowing dates, crop density, soil fertility management, weed control, pests and diseases control, water conservation measures (Pala and Studer, 1999). Appropriate varieties need first to manifest a strong response to limited water applications and they should maintain some degree of drought resistance. In addition, the varieties should respond to the higher fertilizer rates and resist lodging, which can occur in traditional varieties under irrigation and fertilization. Delaying the sowing date prevents crop germination and seedling establishment because of the rapid drop in air temperature starting generally in November. Given the inherent low fertility of many dry-area soils, judicious use of fertilizer is particularly important. To obtain the optimum output of crop production per unit input of water, the mono-crop WP should be extended to a multi-crop WP (water productivity). Water productivity of a multi-crop system is usually expressed in economic terms such as farm profit or revenue per unit of water used. While economic considerations are important, they are not adequate as indicators of sustainability, environmental degradation and natural resource conservation

5.1.8 Early planting of paddy should be stopped.

The evapo-transpiration losses of water in rice fields depend on the temperature and relative humidity in the atmosphere. Since the months of May and June experience hot and dry climatic conditions, the evapo-transpiration losses are expected to be the highest. Therefore, the rice transplanted during the month of May or first fortnight of June, may consume higher volume of irrigation water due to increased evapo-transpiration losses. The Punjab Agricultural University, Ludhiana recommends that rice should be transplanted in the second fortnight of June. Rice variety PAU-201, can be transplanted even up to 5th of July. It is one of the effective strategies to arrest the falling water table in the rice growing state. The evapo-transpiration losses can be reduced by 25-30% by delaying of transplanting of paddy beyond 10th of June in Northern India.

5.1.9 In case of limited water availability, irrigation should be provided during critical growth stages of crop.

When the water supply is very limited, the crops are irrigated only at critical stages. Following are the important crops need to be irrigated at critical stages.

- Rice

When the water resources are limited, the land may be submerged at least during the critical stages of growth, viz. tillering and flowering, and maintained only saturated at other stages.

- Wheat

The optimum soil-moisture range for tall wheat is from the field capacity to 50% of availability. The dwarf wheat need more wetness, the optimum moisture range is from 100-60% of availability. The active root-zone of the crop varies from 50-75 cm according to soil type. The critical stages during the growth are crown-root initiation (three weeks after sowing) flowering and grain development.

- Barley

Barley is similar to wheat in its growth habit. The active root-zone of barley extends to 60-75 cm. on different soil types. The optimum soil moisture ranges from the field capacity to 40%

of availability. About two irrigations are adequate on sandy-loam soils. The critical stages for water requirement are early tillering, boot stage, grain filling.

- Maize

The optimum soil-moisture range is from 100-60% of availability in the maximum root-zone which extends from 40-60cm on different soil types. The critical stages of growth are the early vegetative period (30-40 days after sowing) and tasselling (45-50 days). In the northern parts, two or three irrigation is required to establish the crop before the on set of the monsoon.

- Sorghum and Other Millets

The optimum moisture range is from the field capacity to 40% of availability. The sorghum roots can extend down to 100-150 cm. but other millets have shallow root system extending to 30-45 cm. in the soil profile. Pre-flowering (boot stage) and grain development are the two critical stages in respect of moisture. The crop should be irrigated at least at the critical stages to maintain optimum moisture in the root-zone during the dry spell.

- Pulses or Grain Legumes

Important Kharif legumes are cowpeas, green-gram, black-gram, kidney-bean and pigeon-pea. When grown along, one or two irrigations would be beneficial to boost their yields. Critical periods in the legumes are the early vegetative growth, flowering and pod development.

- Oilseeds

The principal oilseeds are groundnut, sesamum and niger during Kharif and safflower, mustard, castor and linseeds during Rabi. Maintaining moisture in the range of 100-50% of availability by one or two supplementary irrigations increases their yield more than double. In case of groundnut 8-10 irrigation of about 50 mm each are applied at 10-15 days intervals during its growth period (critical stages-pegging to pod formation). Safflower, Mustard and Linseeds should receive 3-4 irrigation during their growth. Branching (30-40 days after sowing) and flowering (60-70 days from sowing) are the critical stages with respect of moisture stress.

- Cotton

The optimum range of soil moisture for the crop is from the capacities to 20% of availability in 0-75 cm. of the root-zone. On sandy-loam soils two pre-flowering, two in flowering and one post-flowering irrigation have been found to be optimum. In the black soil of Gujarat 2-3 irrigation have been found to be adequate. Optimum soil moisture is necessary during the stages of flowering and boll formation. On heavier soil it is preferable to alternate furrows for maintaining better aeration.

- Jute

The optimum moisture regime is from the field capacity to 70% of availability in the maximum root-zone of the crop which extends to about 45 cm. of soil depth.

- Sugarcane

The optimum moisture for sugarcane is 100-50% range of availability in the maximum root-zone, extending upto 50-75 cm. in depth. Since only vegetative growth is of economic importance, a good crop should never suffer from moisture stress during its growth.

5.1.10 Promotion of Conjunctive use of ground and surface water.

Conjunctive use of surface and groundwater consists of harmoniously combining the use of both sources of water in order to minimize the undesirable physical, environmental and economical effects of each solution and to optimize the water demand/supply balance. Usually conjunctive use of surface and groundwater is considered within a river basin management programme i.e. both the river and the aquifer belong to the same basin.

Assuming that the mixed solution is part of the national policy, several problems need to be carefully studied before selecting the different options and elaborating a programme of conjunctive use of surface and groundwater:

- Underground storage availability to be determined,

• Production capacity of the aquifer(s) in term of potential discharge,

• Natural recharge of the aquifer(s)

• induced natural recharge of the aquifer(s)

• Potential for artificial recharge of the aquifer(s)

• Comparative economic and environmental benefits derived from the various possible options.

5.1.11 Efficient and reliable communication network

For management of large irrigation system, there are many options are available for speedy communication of information. In the earlier systems, telephonic as well as telegraphic communication was practiced. However, in the present day context there are more advanced techniques such as satellite communication which may be adopted appropriately.

5.2 LONG TERM MEASURES

5.2.1 Land consolidation and land reforms

Fragmentation of land holding is one of the reasons for low irrigation efficiency. Land consolidation is a planned readjustment and rearrangement of land parcels and their ownership. It is usually applied to form larger and more rational land holdings. Land consolidation can be used to improve the rural infrastructure and to implement the developmental and environmental policies (improving environmental sustainability and agriculture) (Pasakarnis and Maliene, 2010). Land consolidation, as a process that requires the preservation of each farmer's wealth in land when fragmented plots are exchanged, is usually not considered land reform.

Land reform usually refers to redistribution of land from the rich to the poor. More broadly, it includes regulation of ownership, operation, leasing, sales, and inheritance of land. Consolidation and/or realignment are possible today because of modern construction methods. Better irrigation system features such as improved water control structures and lining and piping materials also make consolidation and/or realignment practical as effective water conservation measures. Benefits include: (1) reduced operation and maintenance activities for water users, (2) improved farm unit layout, (3) elimination of weeds along deleted waterways, (4) improved service to water users, (5) improved economic use of the land, and (6) reduction of diversion requirement

5.2.2 Seepage control in vulnerable sections of minors, water courses & field channels on priority

Various techniques have been tried to reduce losses of irrigation water. Two major sources of losses, particularly from surface supplies and surface systems, are evaporation and seepage from reservoirs and canals. Many studies have been made of techniques to suppress evaporation. One of the more promising appears to be application of a special alcohol film on the surface, which retards evaporation by about 30 percent and does not reduce the quality of the water. The primary problem in its use is that it is fragile; a strong wind can blow it apart and expose the water.

5.2.3 Proper land shaping/modifications

a) Land leveling: Unevenness in the soil surface adversely affects the uniform distribution of water in the fields. Now a day it is possible to do Precision land leveling on the fields, which seems to be leveled with naked eyes, with the help of Laser leveller which gives much better results than the earlier devices. Benefits of Laser leveling are:

i. More level and smooth surface.
ii. Reduction in time and water required to irrigate the field.
iii. More uniform distribution of water in the field.
iv. More uniform moisture environment of the crops.
v. More uniform germination and growth of crops.
vi. Improved field traffic ability.

The technology helps in saving of irrigation water by 20-30 per cent and ensures better crop stand due to even application of fertilizers and other inputs and hence results in the improvements in crop yield by 5-10 per cent.

5.2.4 Rehabilitation works

The rehabilitation works aimed to overcome water losses within the distribution network are sine-quo-non for effective use of the irrigation infrastructure.

5.2.5 Capacity building at all concerned levels including planners, managers, stakeholders, and end users

Capacity building programs will impart knowledge on advanced irrigation techniques and modern irrigation tools. These programs will also create awareness among irrigation planners, managers and stakeholders.

5.2.6 Limited automation of irrigation for adoption in future in phase wise manner.

Automation of irrigation system refers to the operation of the system with no or minimum manual interventions. Irrigation automation is well justified where a large area to be irrigated is divided into small segments called irrigation blocks and segments are irrigated in sequence to match the flow or water available from the water source.

The overall water use efficiency of a manually operated system, exclusive of the use of any return flow, seldom exceeds 40 percent. It is reasonable to expect an increase of the overall efficiency of about 10 percent or more for a system with some automation. The advantages of automation are not limited to savings in operation cost and in water. It also alleviates the risk of water logging and salinization. A further advantage is that it increases the reliability and accuracy of water distribution. This contributes to the establishment of a climate of confidence between the operating authority and the farmers, which in turn contributes to the effective organization of water user groups and their participation in operation and maintenance activities. With automation, it may also be possible to accurately know the volume of water delivered to individuals or groups of farmers. This makes possible the introduction of volumetric water charges, combined or not with a system of annual volumetric allocation. This approach is a useful tool for encouraging farmers to optimize the use of limited water allocations and to increase productivity.

Improvements in automatic control equipment have greatly expanded the field of canal operation and control. Automation has become a common term when discussing modern canal systems. `Automation' is defined as a procedure or control method used to operate a water system by mechanical or electronic equipment that takes the place of human observation, effort and decision; the condition of being automatically controlled or operated. Automating a canal system is therefore implementing a control system that includes automatic monitoring or the control equipment that upgrades the conventional method of canal system operation. Automation is used to simplify and reduce or replace the decision-making process of the operators and to implement a decision. It is increasingly used to improve the effectiveness and to reduce the cost of water supply system operations.

Automation of distribution canals becomes essential for optimum conditions. The process must not be dismissed out of hand as too expensive. Its economics must be studied, keeping in mind that reduced on-farm costs and water requirements, and increased yields and management capabilities, provide savings that usually will more than make up for increased project costs. Reduction of project operation costs and water loss is also a benefit of automation and is usually the only one considered. It is also required to install suitable soil moisture sensing device such as Tensiometer, Gypsum blocks etc. for desired scheduling of irrigation water application, so as to minimize deep percolation losses.

5.2.7 Application of remote sensing data for soil moisture monitoring.

Surface soil moisture is one of the crucial variables in irrigation water management, which influences the exchange of water and energy fluxes at the land surface/atmosphere interface. Accurate estimate of the spatial and temporal variations of soil moisture is critical for irrigation scheduling. Recent technological advances in satellite remote sensing have shown that soil moisture can be estimated by a variety of remote sensing techniques (optical, thermal infrared, microwave passive). Microwave remote sensing is the most effective technique for soil moisture estimation, with advantages for all-weather observations and solid physics (Wang & QU, 2009).

5.2.8 **Regional based pilot studies should be planned to study the different aspects of irrigation efficiency.** Tentatively it is proposed to conduct elaborate field measurements in three selected command areas of Haryana/Punjab, Assam/Orissa, Madhya Pradesh/Chhattisgarh. These field measurements will serve as bench mark level for introducing various improvements for testing enhancement of irrigation by 20% at least. The above consultancy project can be taken up by the same team from IIT Roorkee entrusted with the present assignment.

Above recommendations have emerged during Brain Storming Session at NIH Roorkee on February 21, 2011. In this Brain Storming Session Shri G. Mohan Kumar, I.A.S., Additional Secretary, Ministery of Water Resources (MoWR) suggested for holding a meeting with ICAR officials for further refinement. In light of the above on May 24, 2011, a meeting on the above subject was held at ICAR, Krishi Anusandhan Bhawan-II, New Delhi -110 012. Points related to irrigation efficiency were discussed.

6. ACKNOWLEDGEMENT

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