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Water management issues at the farm level

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Abstract

The growing water scarcity in India is focussing the spotlight on improving water use efficiency and productivity in the irrigation sector which uses by far the largest proportion (over 80 percent) of the total abstracted water. Due to the scale of water use relatively small improvements in efficiency and productivity in this sector have potential for relieving the pressure on scarce resources and releasing water for other uses or users.

There is currently much discussion in India about introducing drip and sprinkler irrigation as these are perceived as being more efficient than surface (flood) irrigation. However data from the USA and Australia show that sprinkler and drip irrigation account for only 57% and 56% of the total irrigated area respectively, with the remaining 43% and 44% being surface irrigated. In these two countries only 6% and 13% of the total irrigated area respectively is under drip irrigation. In South East and South East Asia it is estimated that 94.9% of the total irrigated area is under surface irrigation, 2.4% under sprinkler and 0.7% under drip irrigation, with a further 2.0% undefined (FAO Aquastat data, accessed March 2015). These figures indicate that surface irrigation will be the dominant method of irrigation In India and South Asia for the foreseeable future.

In addition. studies on actual irrigation efficiencies in Australia show that the highest efficiency in surface irrigation (range 60-**85**%) is higher than the lowest efficiency in sprinkler irrigation (range **60**-90%) and also higher than the lowest efficiency in micro irrigation (range **75**-95%). The gap between achievable irrigation efficiencies in surface irrigation and the commonly quoted low efficiencies of only 30-40% for surface irrigation in India thus indicate a significant opportunity for improvement, at a relatively lower capital invest and operating cost as well as a far lower energy and carbon footprint than sprinkler and drip irrigation.

This paper argues the case for increasing the focus on improving surface irrigation. It describes measures that have been taken on World Bank funded projects in Madhya Pradesh and West Bengal to improve the efficiency and productivity of surface irrigation at the field level. These measures include research into ways to improve the productivity of irrigation water through improvements in agricultural processes, and measures to assess and reduce distribution and application losses.

Work carried out to date shows a significant gap in understanding and knowledge of basic water management practices at the field level, both amongst farmers and government field staff. Pragmatic and practical training material and courses, including Farmer Field Schools, have been developed to address this knowledge gap. The paper concludes that in recent years the tendency has been to focus on introducing pressurized irrigation (sprinkler and drip) whilst ignoring the significant and more widespread opportunities available for improving surface irrigation. It closes with a proposed action plan for addressing this oversight and significantly improving both water use efficiency and productivity through adoption of modern surface irrigation practices.

1.0 Introduction

India is facing a growing water crisis and with the majority of the abstracted water being used for irrigation the spotlight is being focussed on reducing wastage of water to increase efficiency and productivity of water in irrigation schemes. Surface (flood) irrigation is the most widely used irrigation method in India yet scant attention is being paid to measures to improve application efficiencies at the field level. Measures that are being talked about relate to converting surface irrigation systems to pressurized irrigation (sprinkler and drip), but in reality these measures are (a) costly and (b) insignificant in comparison to the size of the surface irrigated areas.

This paper puts the case for improving surface irrigation practices and argues that in comparison to sprinkler and drip irrigation such measures are less costly and will produce greater water savings without the increased energy demands and carbon footprint associated with pressurized irrigation systems. The observations made are based on field work carried out over the last 6-7 years on World Bank funded irrigation projects in Karnataka, Madhya Pradesh, West Bengal, Odisha and Tamil Nadu.

2.0 Background

It is well documented that India is facing a water crisis in the coming years (2030 WRG, 2009; Amarasinghee et al, 2004; 2007). Under the National Action Plan for Climate Change (NAPCC) the National Water Mission was one of eight key areas requiring strategic interventions. In its guiding document (NWM, 2011) the Mission identified various strategies leading towards integrated planning for sustainable development and efficient management of the nation's water resources. The Mission's concern was that climate change and changes in land use will affect the quantity and quality of the available water resources.

This concern has led to the development of a strategy for mitigation and management with five identified goals: (i) creation of a comprehensive water data base in the public domain and assessment of the impact of climate change on water resources; (ii) promotion of citizen and state action for water conservation, augmentation and preservation; (iii) focused attention on vulnerable areas including over-exploited areas; (iv) increasing water use efficiency by 20%, and (v) promotion of basin level integrated water resources management.

The Mission's Comprehensive Mission Document (NWM, 2011) sets out in detail the strategies and actions to be followed to achieve the above goals, with each strategy seeking to address key areas of concern highlighted in the NAPCC. Amongst the actions proposed in the CMD were measures to improve water management at the farm level by:

- Significantly increasing water use efficiency by improving field irrigation methods (graded border, furrow, surge irrigation, pressurised irrigation, etc.);
- Adoption of scientific water management practices, including determining and matching actual crop water needs rather than applying water duties, adoption of more efficient irrigation scheduling policies and rules;
- Mass awareness campaigns to advise farmers on improved irrigation scheduling;
- Ensuring adequate and timely irrigation water supplies through the use of modern technology, processes and procedures;
- Giving more responsibility to users' groups in the management, operation and maintenance of I&D schemes, including promotion and support for participatory irrigation management;
- Paying greater attention to managing conjunctive use of surface and groundwater resources.

This paper looks at measures being taken under the World Bank funded projects in India to address the need to increase water use efficiency and productivity at the farm level, in large part by adopting the recommendations outlined above.

One area of concern is that there is a perception that the answer to the water crisis in India is to move to drip and sprinkler irrigation. However, whilst these technologies offer benefits in *some* situations they are not a panacea for solving the crisis. At a recent training session on the Accelerated Development of Minor Irrigation Project (ADMIP) in West Bengal participants were asked what they thought the percentage area was under drip and sprinkler irrigation in the USA and Australia. The response was "95 percent". This is far from the case, as Table 1 below demonstrates. As can be seen the micro irrigation covers only 6.1% and 13.3% of the total irrigated areas in the USA and Australia respectively, with a much larger area under sprinkler irrigation. However, even in the USA and Australia the area under surface irrigation is appreciable at around 44%, and some 7 times (in the USA) and 3 times (in Australia) time greater than the area under drip irrigation.

Several key points arise from these data:

- Drip and micro irrigation are only suitable for a limited range of, mainly, horticultural crops (with the exception of sugar cane). They are not appropriate for the major grain crops of wheat and rice;
- Even in the USA and Australia, generally considered as countries well-advanced in irrigation terms, surface irrigation plays a central role;
- The area under micro irrigation is relatively small, only 6-13% of the total

Table 1: Summary of irrigation technology use in USA and Australia

Country	Irrigation Method (%)			Irrigated
	Surface	**Sprinkler**	**Micro**	**Area (ha)**
USA in 2003	43.4	50.5	6.1	21,591,000
Australia, 2008-09	44.0	42.7	13.3	1,826,000

Sources: Hoffman et al 2007 and Government of Australia NWC. 2011

As can be seen from the data presented in Table 2 there are certainly opportunities in South and East Asia for increasing the areas under sprinkler (currently estimated as less than 2.4%) and drip irrigation (currently estimated as less than 0.7%) but for the foreseeable future the predominant irrigation method will be surface irrigation (currently estimated as more than 94%).

Table 2: Regional summary of irrigation technology use

Region	Irrigated area				
	Total	**Surface**	**Sprinkler**	**Drip**	**Undefined**
	Ha	**Ha**	**Ha**	**Ha**	**Ha**
(a) Area					
Africa	9,342,237	7,126,919	1,620,545	594,773	
Central Asia	12,360,331	12,161,394	183,714	15,223	-
Middle East	19,207,142	16,339,334	1,950,727	917,081	-
South America and Caribbean	17,752,097	12,948,558	3,782,241	1,021,298	-
South and East Asia	180,480,311	171,229,276	4,335,757	1,348,729	3,566,549
Total			**11,872,984**		**3,566,549**

239,142,118	**219,805,481**		**3,897,104**	
(b) As percentage of area	**%**	**%**	**%**	**%**
Africa	76.3%	17.3%	6.4%	0.0%
Central Asia	98.4%	1.5%	0.1%	0.0%
Middle East	85.1%	10.2%	4.8%	0.0%
South America and Caribbean	72.9%	21.3%	5.8%	0.0%
South and East Asia	94.9%	2.4%	0.7%	2.0%
Total	**91.9%**	**5.0%**	**1.6%**	**1.5%**

Note: Data taken from FAO Aquastat - http://www.fao.org/nr/water/aquastat/tables/index.stm (accessed March 2015)

Source: IWMI, 2015

IWMI (2015) report that in Australia a review of technology change in the irrigation industry found a large range in the actual irrigation application efficiencies for different irrigation methods:

- Drip and micro-irrigation 75-95%
- Sprinkler 60-90%
- Surface 60-85%

Thus the highest surface application efficiency (85%) was higher that the lowest sprinkler application efficiency (60%) and also higher than the lowest drip application efficiency (75%).

Each of the irrigation methods has a number of attributes and limitations, as discussed below:

Pressurized irrigation (sprinkler and drip) are often used when irrigating high value crops (e.g. fruit and vegetables) and where water is being pumped anyway, such as from groundwater or river lift. Sprinkler is also economic where there is rolling topography not suited to levelling for surface irrigation. However sprinkler and drip irrigation systems are expensive in terms of capital investment and operational costs and require relatively skilled farmers and effective support services. Sprinkler is suited to broad-acre crops, whilst drip is better suited to row and tree crops. A particular concern with drip irrigation is that salts may not be leached from the soil due to the high application efficiencies. A significant difference between drip and other irrigation methods, including sprinkler, is that it provides daily irrigation to the crop's root zone and does not rely on the soil moisture holding properties to store water between irrigations. As the water is piped for both surface and drip irrigation the distribution losses are negligible.

Surface (flood) irrigation takes a number of forms, the most common being basin, furrow and border strip. Key features of surface irrigation methods in relation to water use efficiency are that (i) water is generally conveyed to the plot via open channels (lined or unlined), (ii) water has to travel horizontally across the soil to irrigate the plot, and (iii) irrigation is intermittent and thus water has to be stored in the soil. For basin irrigation the land within the plot has to be level and the intention is to flood the basin as quickly as possible to avoid differences in contact time over the basin. For furrow and border strip the flow size per furrow or per unit for border strip is tailored to match the soil's infiltration rate and the land slope, with the intention being to balance the surface flow rate with the vertical infiltration into the soil such that a uniform depth of application is given across the plot. The choice of irrigation method depends on a number of factors, including the crop type, topography (slope and uniformity) and plot size. Table 3 summarises the key factors influencing the choice of surface irrigation method.

Table 3: Factors influencing choice of surface irrigation method

Surface irrigation method	Key features	Crop types	Remarks
Basin	Land must be level within the basin	Predominantly used for rice with follow-on crops such as wheat, soybean, groundnuts.	Water is ponded for paddy rice. For dry foot crops such as wheat requires a high irrigation flow rate to flood the field as quickly as possible to reduce unequal application.
Furrow	Ridged furrows down the predominant slope. Suitable for land with a slight cross slope.	Row crops, including maize, sunflower, sugarbeet, vegetables and potatoes. Also used for orchards.	The irrigation flow rate needs to be matched to the soil type and land slope to avoid unequal application.
Furrow in basin	Often used in small basins for row crops and vegetables	Row crops, including maize, sunflower, sugarbeet, vegetables and potatoes.	Relatively labour intensive but enables precise irrigation with high efficiency.
Border strip	Requires a uniform plane in the direction of irrigation.	For irrigation of close growing crops such as wheat and barley	The irrigation flow rate per unit width needs to be matched to the soil type and land slope to avoid unequal application. The width of the strip can be adjusted to suit the discharge available to maintain the required flow rate per unit width.

3.0 Key issues at the farm level

One of the key issues in improving the irrigation efficiency and water productivity at the field level is the sheer number of farmers whose irrigation practices need to be changed if water is to be conserved and used more productively. On the other side of the coin is the fact that due to the large numbers a relatively small change in individual farmer behaviour could result in significant overall water savings. The issue thus becomes one of sustained mass education and awareness to modernize surface irrigation practices. Table 4 provides data which shows the scale of the problem facing public sector irrigation schemes in South Asia, with some 270million farmers identified as economically active in India.

Table 4: Potential and actual irrigated area, estimate of number of farmers, and contribution to GDP in South Asia

Country	Potential irrigated area (M ha)	Area irrigated (M Ha)	Economically active in agriculture (million)	Estimated contribution to GDP (%)
Bangladesh	6.93	2.74	32.15	17.2
India	139.50	62.29	273.66	18.2
Nepal	2.17	1.17	11.54	35.1
Pakistan	21.30	19.27	25.90	25.3
Sri Lanka	0.57	0.46	4.01	10.8

Notes: 1. GDP – gross domestic product, M ha – million hectare
2. Data abstracted from FAO AQUASTAT database, 2015
Source: IWMI, 2015

From work carried out on World Bank funded projects in Karnataka, Madhya Pradesh, West Bengal, Odisha and Tamil Nadu it is apparent that there is a lack of understanding and knowledge amongst field staff in the Water Resources Department (WRD) and Agricultural Departments of field irrigation theory and practice.

Irrigation management at the field level seems to fall between the two stools of water supply and agriculture. WRD staff rarely intervene in water management practices at the field level, whereas Agricultural Department staff tend to focus on issues related to the crops (crop selection, seed variety, crop husbandry, weeding, fertilizer usage, and crop pests and diseases). How and when the water is applied to the crop is generally not considered, and rarely the subject of extension advice and training. Questions such as:

- when and why the farmer decides to irrigate;
- how much he/she applies during each irrigation
- what flow rates are used and
- what is the depth and uniformity of each irrigation

are rarely, if ever asked by field staff. This lack of engagement with water management at the field level stems from a basic lack of interest, understanding and knowledge of the basic principles of irrigation principles and required practices at the field level.

Case Studies

(a) West Bengal I

During a visit to Pachgachiya scheme in Hoogley District, West Bengal a demonstration was carried out of an approach to ascertaining the depth of irrigation water to be applied to a field of sesame crop (Figure 1). The soil type was identified from a simple field test which comprises rolling and shaping a moist soil sample (Figure 1 a). A single ring infiltrometer was set up and filled with 10 cm of water which was allowed to infiltrate into the soil. The farmers present were asked two questions (a) how long would it take the water to infiltrate into the soil and (b) how deep would the water go into the soil. The answers to (a) ranged from 6 to 15 minutes, and to (b) from 10 to15 cms. In the event the water took over 2 hours to infiltrate fully and penetrated to a depth of 30cms (Figure 1e), with the depth of penetration being ascertained by augering through the wetted zone under the infiltrometer. A sesame plant was dug up to determine the root depth, the main mass of the root system was in the top 15cm of the soil, implying that an application depth of 10cm would result in over-irrigation beyond the root zone by 15cm, and a 50% application efficiency.

Several lessons emerged from this demonstration and discussions with field staff:

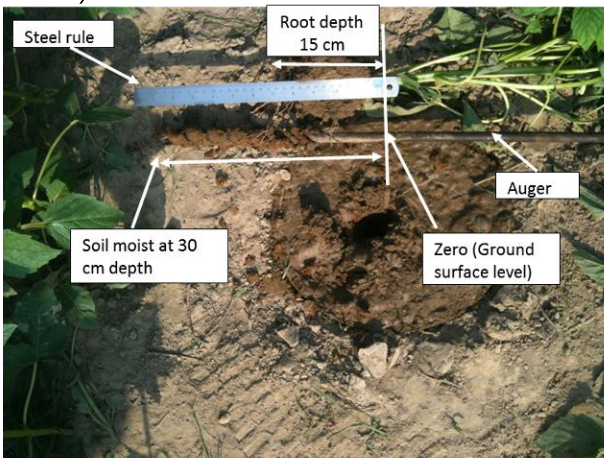
- None of the farmers had ever checked to see how far the irrigation water infiltrated into the soil. They applied the water “by feel” based on the duration of irrigation;
- The majority of the project staff had never seen an infiltration test or used an auger to ascertain the depth of irrigation. One or two of the agricultural staff had carried out an infiltration test during their college days, neverdurng their working lives;
- Even though they had been irrigating these soils for many years the farmers’ estimates of how long it would take the water to infiltrate into the soil and to what depth were quite far out from the measured situation;
- Though farmers were aware that different soils might take different times and quantities to irrigate they could not quantify the difference;
- For both farmers and project staff the exercise was something of a revelation which provoked much discussion and interest.

(a) Identifying the soil type and thus the infiltration rate and water holding capacity

(b) Marking up the screw auger in 10 cm sections

(c) Ponding 10 cm of water on the soil. Farmer's estimate of time to infiltrate varied from 6-15 mins, in fact took 3 hours (silty clay loam soil - good clay content in the soil).

(d) All the water had infiltrated after 2 hours, surface still saturated. WUA secretary augered down through the centre to see the infiltration depth.



(e) Soil water infiltrated 30 cms, root boll of sesame crop was 15 cms

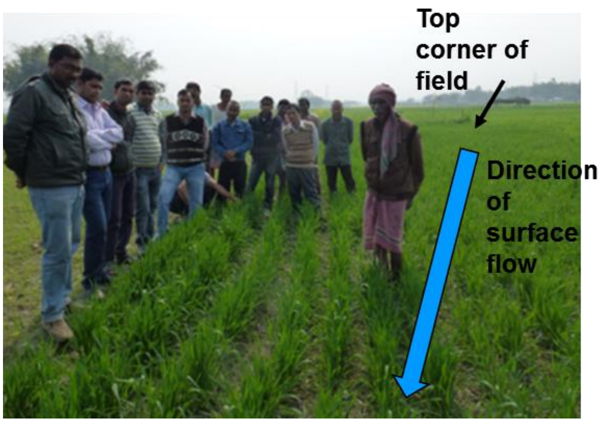
Figure 1: Field-based demonstrations for water management, West Bengal, April 2015

(b) West Bengal II

During a field trip on the Accelerated Development of Minor Irrigation Project (ADMIP) in West Bengal in February 2016 the following practices were observed. A farmer had irrigated a 5 bighar field of wheat with a discharge of between 10-14 l/s (Figure 2). The water was provided from the tubewell via buried pipes to a spout, and then via a lay flat pipe to the head of the field. The soil was identified as a loam.

According to the farmer he had irrigated the field for 2 hours, with the water taking 1½ hours to reach the end of the plot. From calculations of the cumulative infiltration rate and a target application depth of 85 mm the application efficiency was estimated as 64% (Figure 2b,c,d) The large difference in the contact time between the top and tail end of the field (Figure 2e) due to the relatively small flow rate entering the field is a matter of concern, with cumulative infiltration ranging from 106 mm depth at the top of the field to only 39mm depth at the tail.

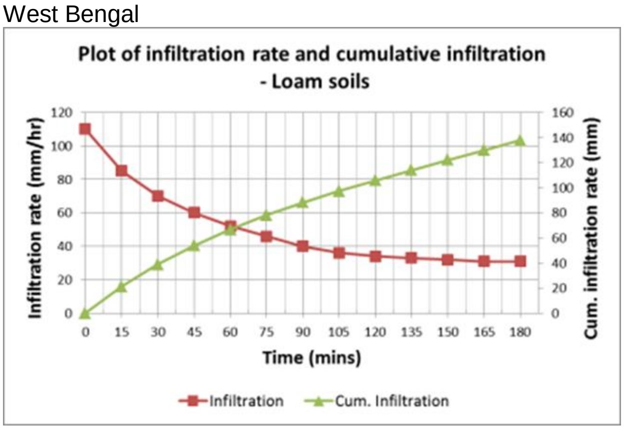
In this example the application efficiency and distribution uniformity could be measurably improved by simple measures, as outlined in the following sections.



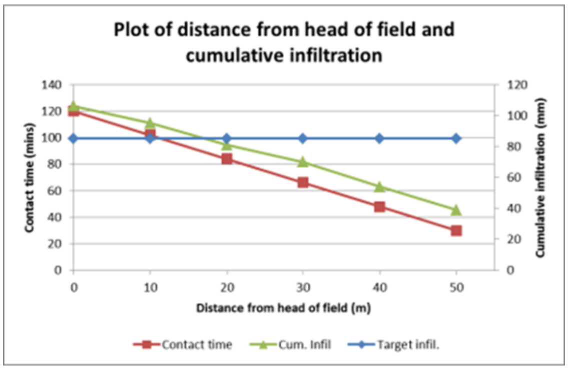
(a) Farmer's plot irrigated with flow from a lay-flat pipe connected to the spout. Irrigation from top right corner of field takes 1.5 hrs to reach bottom of field. Irrigation stopped after 2 hours. Plot has an agricultural demonstration of line sowing of wheat. Bhangarat Jatileswar Krishi Unyanyan WUA, Jalpaiguri District, West Bengal

Contact time vs Distance in field				
Distance in field	Wetting front	Contact time	Cum. Infil	Target infil.
(m)	(mins)	(mins)	(mm)	(mm)
0	0	120	106	85
10	18	102	95	85
20	36	84	81	85
30	54	66	70	85
40	72	48	54	85
50	90	30	39	85

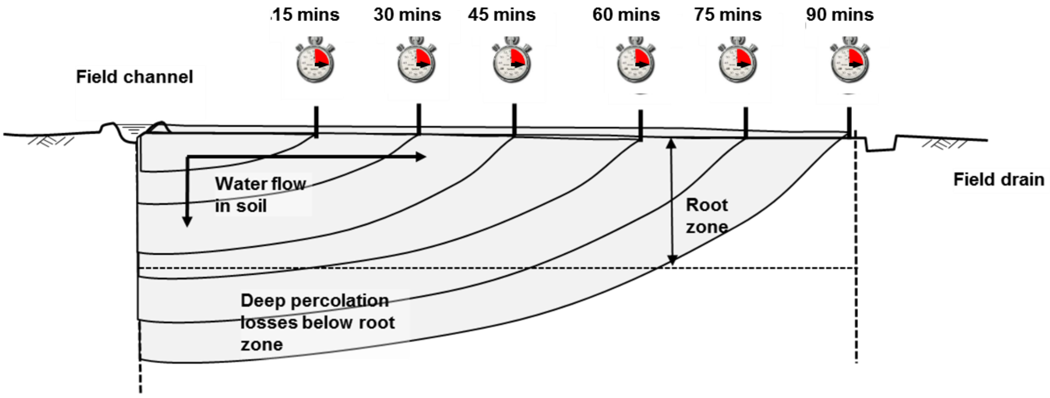
(b) An estimate of the contact time versus advance front of water in the field shows a range of 106 mm infiltration in top-end of field and only 39 mm infiltration in bottom end of field



(c) Plot of infiltration rate and cumulative infiltration data shown in (b)



(d) Plot of target depth (85 mm), contact time and cumulative infiltration showing the disparity in infiltration between head and tail of the field



(e) Graphic showing the problem of deep percolation below the root zone at the top-end of the field and under-irrigation of the tail-end.

Figure 2: Example of uneven water application at the field level

Allied to the above poor application practices is the issue of uneven fields which leads to uneven irrigation and low application efficiencies (Figure 3). In these cases laser land levelling offers opportunities for improving water use efficiency and productivity.

(a) Large uneven fields which would benefit from laser land levelling. water application, Shikara-I LDTW irrigation scheme

(b) Wide spacing of irrigation channels and poor tillage of soil results in low application efficiencies and uneven/poor crop growth, Shikara-I LDTW irrigation scheme

Figure 3: Uneven field leading to poor application efficiencies and poor distribution uniformity

Case Study III – Odisha

A water management study was carried out in February 2014 on 7 minor tank schemes in Odisha to better understand how the Water Users Associations and farmers managed their irrigation water (OCTMP, 2014). The recommendations arising from this study included:

- A need for a greater focus on capacity development of the WUA in water management;
- Greater convergence with agriculture and horticulture to make more productive use of the available water resources;
- Increasing the canal lining in the parent canal to allow for more efficient and more equitable distribution of irrigation water;
- A fundamental review of the current proportional design principles and practices;
- Increased levels of control and measurement to more closely match with farmers current practices;

- Simplified measures for determining the volume of water in the tank and planning of irrigation area and water allocation.

Whilst there were functioning WUAs which managed the allocation and distribution of water and which had earned the respect of the community there was room for improvement in their processes and procedures, particularly in relation to pre-season planning, recording of cropping and irrigation events and quantification of the available water stored in the tank. Canal lining was found to be particularly beneficial, not only for reducing seepage losses but also for allowing more rapid movement of water around the command area. This was particularly beneficial in systems where water was distributed "on-demand" to individual farmers as it saved considerable conveyance losses and time. In some cases water users had constructed their own canal lining, with assistance from the Department – in one instance the WUA had borrowed steel shuttering from the Department to form the lining.

Control and measurement was a weakness in all canal systems, with insufficient cross regulation, gates and no measurement. There were open breaches in the main canal as outlets and farmers were using stones and sandbags for cross regulation and mud to close outlets (Figure 4). The study concluded that a radical re-think is required if water management is to be improved at the on-farm level, which would also include re-thinking the basic design principles of fixed rotational irrigation supply.

(a) Ungated pipe outlet closed off with mud

(b) Opening canal outlet by removing the mud

(c) Stones acting as cross regulator in main canal

(d) Informal cross regulator and slotted offtake

Figure 4: Examples of inadequate water control in canals

4.0 Proposed solutions and action plan

The problems outlined above range from design to management and application of water to the crop root zone.

On-farm water management

Good water management at the on-farm level comprises three factors related to the level of control available to enable the right amount of water to be applied to the crop at the right time and in the right quantity:

i) **Social control** – the ability to control who takes water, when and where. Social control is required to ensure that water allocation and distribution is fair, and that head-enders do not take water at the expense of tail-enders.

ii) **Management control** – is required to allocate and distribute water to match the farmers' demands. Management control is provided by the WUA Executive Committee , with the endorsement of the General Body.

iii) **Physical control** – is needed to be able to implement the agreed irrigation schedule to apply the right amount of water at the right place. Gates and cross regulators are key items in physical control of irrigation water delivery, but require social control to ensure that farmers (especially those at the head-end) follow the agreed rules and schedule.

Without these three types of control it is not possible to irrigate efficiently. Box 1 provides an example of a successful farmer-managed system with a high level of control.

Box 1: Example of good physical, social and management control of irrigation water

The Pachilagudi Minor Irrigation Project in Nayagarh District in Odisha exhibits the three forms of control required for good irrigation management. The features are:

i) **Social control :** The WUA is respected by the farmers and accepted as the body responsible on behalf of the community for management of the water resources.

ii) **Management control**: Through the General Body the farmers have agreed a set of rules for allocation of water whereby farmers requiring water pay for each irrigation to the WUA Treasurer or Vice President before taking the water. The farmer then takes the receipt to the gatekeeper/water master who then opens the sluice gate to supply the agreed volume of water.

iii) **Management and physical control**: The WUA has a paid gatekeeper/water master who is responsible for opening and closing the sluice gate, and for monitoring the flow in the main canal. When he is given the receipt by the farmer he unlocks the sluice gate and opens it to provide the required flow, and checks that the water has been delivered to the farmer's plot. The lined main canal enables good control of the flow from top to tail of the system.

Irrigation water charge record and (yellow) receipt books

Padlocked sluice gate

WUA Executive Committee members inspect the concrete lined Main Canal

Other factors influencing water management include:

i) Irrigation water supplies to farmers should be reliable, timely and adequate to meet crop needs. Reliability is a key factor, and is generally better in tank irrigation systems compared to diversion systems;

ii) Adequate control systems are required in order to provide reliable, timely and adequate irrigation water supplies. These include control gates to control the flow, and cross regulators to control the water level;

iii) Equity and fairness are important factors. These are governed by the physical infrastructure (the canal and its control systems) as well as social behaviour (i.e. how those at the head of the irrigation system behave) and the operation rules. The WUA has a duty to ensure that all members get a fair share of the available water supplies; this particularly applies to those at the tail-end of the system;

iv) Procedures are required for recording farmers' requests for water and converting these into a schedule for irrigation supply. This supply may be for an individual farmer or a group of farmers;

v) For tank systems calculations or estimates based on previous experience should be carried out at the start of the *rabi* irrigation season to assess the volume of water available for irrigation. This can be done by knowing the water level in the tank and using the depth-area-storage curve to obtain the volume available. Once the volume available in the tank is known the area of crops to be irrigated can be determined using figures of crop irrigation water requirements;

vi) In minor irrigation systems managed by WUAs the WUA should organise a General Body meeting before each irrigation season to discuss and agree with farmers (a) the cropping pattern, (b) the rules for water allocation and distribution, (c) the irrigation service fee (water charge) and (d) the list of farmers who will receive irrigation water;

vii) Charging for each irrigation is generally more efficient than charging by crop type and area. Farmers are more careful with water when charged for each irrigation. Charging by duration of irrigation can also improve efficiency;

viii) Open, transparent and accountable procedures are required for setting and collecting the irrigation service fee. The money should be paid by the farmer to the Treasurer or designated Executive Committee member and a numbered receipt issued. This receipt is then handed to the gate keeper/water master as authorisation for water delivery;

ix) The WUA should employ a gatekeeper/water master to manage and oversee the delivery of irrigation water according to the agreed rules and plan, and to periodically check and report on the maintenance condition of the system. During irrigation the gatekeeper/water master should patrol the system to check that the right people are getting the water supplies and that unnecessary wastage is avoided.

During field visits to various systems a good degree of innovation by farmers was observed . These included:

- Farmers connecting lay flat pipes directly to tubewell outlet pipes and spout outlets to convey water to their fields without incurring losses (Figure 5a, b).
- Farmers constructing canal lining at their own cost (Figure 5c, d).
- WUAs closing outlets to a tank (with farmers' agreement) so that the stored water can recharge the groundwater and feed open wells in the command area from which water is then pumped (Figure 5e,f).
- Farmers constructing on-farm storage reservoirs to store water pumped from a borehole. Irrigation is then by gravity flow to fields but with much higher flow rates, thus reducing overall losses and improving efficiency (Figure 5g,h).

(a) Outlet from the tubewell with the flow meter located in the pipe at the top of the concrete pillar, Shikara-I LDTW irrigation scheme, West Bengal

(b) Spout outlet into a chamber, which the farmers have adapted to provide two connections for lay flat pipes, Naskarpur Ghantipara Mini RLI scheme, West Bengal

(c) Well-built farmer-constructed canal lining, OCTMP, Odisha.

(d) Unlined canal section at tail of the same system. No uniform shape, high seepage losses and unable to maintain command at outlets, OCTMP, Odisha.

(e) Open well in command area. Farmers pump from these open wells using a small portable pump and lay flat pipe, as shown in (f), OCTMP, Odisha

(f) Farmer with 2 HP pump and lay flat pipe with tank in the background, OCTMP, Odisha

(g) Combination of borewell and in-field storage reservoir. Water is pumped into the lined reservoir from the borehole and distributed by gravity irrigation to the plots, KCBTMP, Karnataka

(h) Borehole used to supply the storage reservoir, KCBTMP, Karnataka

Figure 5: Farmers' measures to improve on-farm distribution losses

Field level solutions

From extensive field visits to irrigation schemes in a number of states it is apparent that there is limited understanding and knowledge of opportunities for improving water application efficiencies in surface irrigation schemes, both amongst farmers and government staff. There is also very little, if any, quantification of the scale of the problem and the potential water savings and improvements in productivity that can be made at this level. In general agricultural specialists appear to be skilled in agronomic practices (crop varieties, fertilizer application, pest and disease identification, etc.) but poorly skilled in on-farm and field level water management. This has been shown most recently in the World Bank funded ADMIP project in West Bengal where agricultural demonstrations have been established in farmers' fields but with no associated demonstrations of how to irrigate these demonstration plots efficiently.

Thus possible actions and solutions at the field level are seen as being:

i) Raising awareness of the issues and opportunities amongst irrigation and agricultural department staff and enhancing understanding and knowledge of physical processes at this level and measures for improvement.

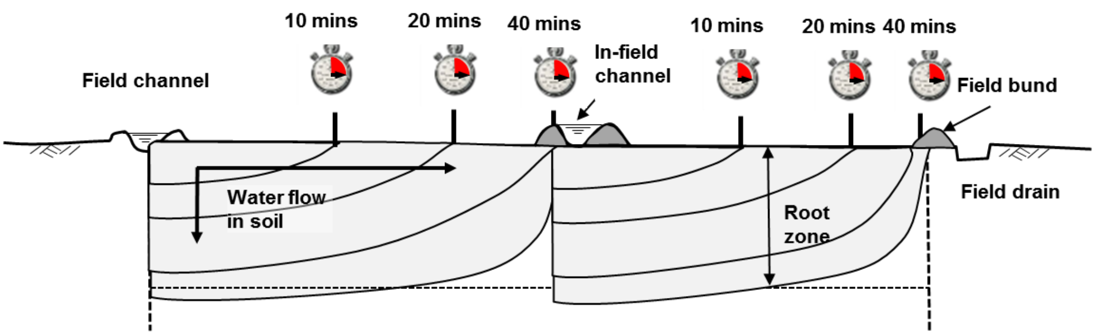
ii) Field level observation and measurement by field staff of farmers' practices and comparison with both theoretical and observed best practice. At present there appears little, if any assessment of farmers' water application practices.

iii) Adoption of simple measures for improvement. One of the simplest approaches is to train WUA management and farmers in the use of hand augers for testing soil moisture status before and after irrigation (as shown in Figure 1). If a farmer normally irrigates his plot for 4 hours and finds on augering that the water is infiltrating 30-40cm below the crop's root zone he can cut back the irrigation duration in stages until he finds the optimum duration required to fill the soil profile in the crop's root zone. This not only saves water, it can save his time, and if he is pumping water, money. In addition saving time will free up water for other farmers to use or conserve water for use at a later date in the case of tank systems.

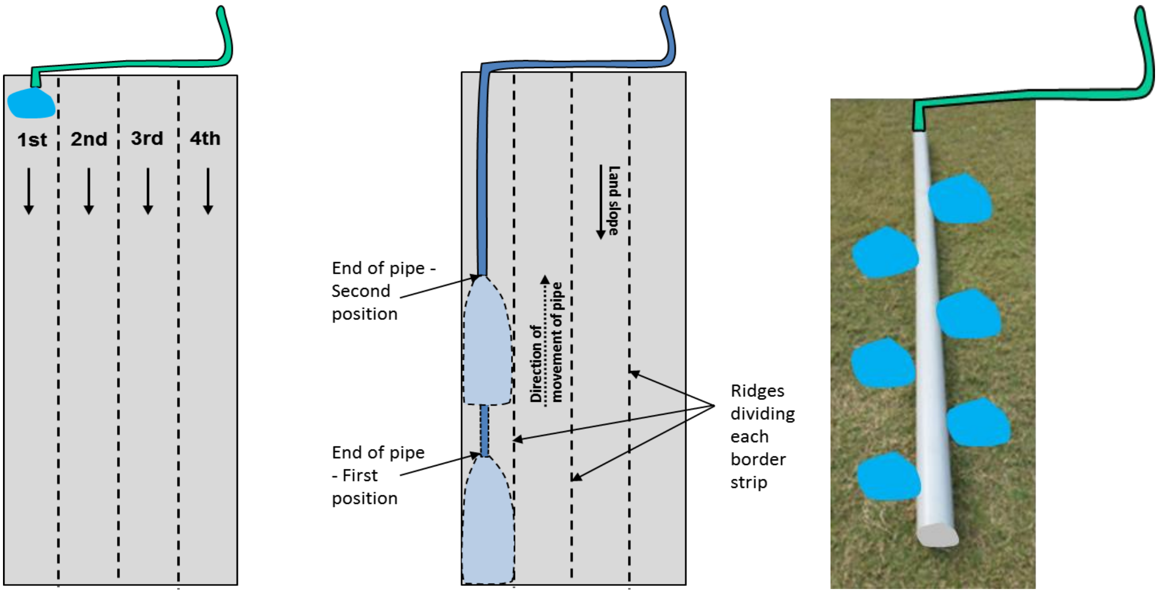
iv) Changing the method of application. Figure 6 shows possible solutions to the problem shown in Figure 2 where there was significant inequality in the contact time (and thus cumulative infiltration) between the top and tail end of the field. In this case the field could be divided laterally into two parts, with each part being irrigated in turn (Figure 6a). Alternatively the field could be divided longitudinally into border strips and each border irrigated in turn (Figure 6b). A refinement of this approach would be to lay the pipe in the field and irrigate the field in several stages, dragging the lay-flat pipe progressively backwards up the field (Figure 6c). A further (untested) option might be to connect the lay-flat pipe to a plastic pipe with holes drilled in it (like a longitudinal gated pipe) and irrigate strips of land at a time (Figure 6d).

In this context the key to identifying what approach is required depends on an understanding of the balance required between the field size, soil type, crop rooting depth, field slope and flow rate such that the longitudinal movement of water over the soil surface is in balance with the vertical flow rate into the soil.

Reduce the difference in contact time by irrigating the field in two halves



(a) Possible solution – divide the field in two for irrigation. Irrigate top half and then move the lay flat pipe to irrigate the bottom half.



(b) Divide the field with small bunds to form 4-5 border strips running down the main slope. Put the pipe in each strip in turn.

(c) Combination of narrow border strips and moveable lay flat pipe which is positioned at different locations in the field, starting from the tail. Best solution with a low flow from the lay flat pipe (<15 l/s).

(d) Possible solution – connect the lay-flat pipe to a 10 cm diameter plastic pipe with 3-4 cm diameter holes drilled in at regular intervals and sealed at the end. Lay the pipe down the field slope to irrigate either side.

Figure 6: Possible solutions for large fields and low irrigation discharge rates

v) Laser land levelling and grading has significant potential for improving performance, as shown by the data provided in Box 2. The benefits of land levelling and grading have been recognised for decades, however until relatively recently the process was expensive and only suitable for large fields. With tractor-drawn levellers controlled by laser beams the process is now relatively cheap and suitable for field sizes down to 0.12 ha (30x40m). Trials are currently ongoing in the Punjab (India) to provide subsidies for contractors and farmers' cooperatives to purchase land levelling equipment to carry out laser land levelling for farmers.

vi) Change the field size. One of the main issues is the relatively small flow rates available to farmers. Reducing the size of the area to be irrigated at one time increases the application efficiency. Options include forming furrows in basins and irrigating 4-5 furrows at a time (Figure 7a) or forming smaller plots to irrigate (Figure 7b,c,d).

Box 2: Impact of laser grading in Pakistan

Research by IWMI on engineered surface irrigation in South East (Pakistan) Punjab for cotton during the summer 2014 season achieved a 12% increase in water productivity (kg/m^3) and an 11% increase in land productivity (kg/ha). This research is ongoing and the experimental field has been planted with wheat for the winter 2014-15 season.

The farmer managing the field trials, based of his observations of substantially improved uniformity of irrigation in the graded furrows, has decided to grow vegetables in place of cotton in summer 2015 to access the better market price.

Source: IWMI, 2016

(a) Furrow-in-basin technique provides greater control of irrigation water application with 4-5 furrows irrigated at a time.

(b) Large field of peanuts with a channel cut through the middle to distribute the irrigation water. Light sandy loam soils with high infiltration rates results in poor application efficiency, poor uniformity and poor yields. Sub-dividing the field into basins with furrow irrigation would greatly improve performance and productivity.

(c) Field plot set out into smaller sub-plots for vegetables, Odisha

(d) Sub-divided field plot for vegetables, Odisha.

Figure 7: Irrigation options for larger fields and low discharges

Improving productivity of water through agricultural initiatives.

On the MP Water Sector Restructuring Project the two agricultural universities at Jabalpur and Gwalior were commissioned to work with project and Agricultural Department staff to improve the productivity of water. The universities carried out adaptive field trials to improve water use efficiency and productivity for soybean, wheat, and paddy, the results of which are presented in Table 5. A range of measures were developed and trialled, including improved seed varieties, seed dressing, improved agronomic practices as well as improved water application methods. As can be seen there are significant opportunities for improving productivity and net margins for these crops through the use of improved agricultural and irrigation practices, with productivity of water improving for soybean, wheat and paddy by 60-87% and increases in net margin ranging from 41-71%. Figure 8 shows some of the opportunities for improved practices through changed agronomic practices.

Table 5: Summary of results of adaptive research trials to improve productivity of water

Crop		Yield(q/ha)		Productivity of water (kg/m3)		Productivity of water (Rs/m3)		Net Margin (Rs/ha)	
		FP	IP	FP	IP	FP	IP	FP	IP
Soybean	Min	4.7	6	0.6	1.1	16.3	32.3	940	8448
	Max	7	10.4	1.3	2.4	31	55.7	14295	26870
	Average	5.7	8.1	0.9	1.6	24.4	42.8	8193	13986
	% change		**43%**		**87%**		**76%**		**71%**
Wheat	Min	18.3	28.7	0.7	1.3	10	18.9	22270	36612
	Max	39.5	54	1.9	3.8	30	56.5	51750	73750
	Average	27.0	37.2	1.1	2.1	17.5	31.6	36159	51112
	% change		**38%**		**82%**		**80%**		**41%**
Paddy	Min	27.6	38.1	4.6	7.5	64.9	105.4	32387	47724
	Max	28	39	5	7.9	69.6	110.1	32500	47913
	Average	27.8	38.6	4.8	7.7	67.3	107.8	32444	47819
	% change		**39%**		**60%**		**60%**		**47%**

FP - Farmers' practice IP - Improved practice

Source: College of Agricultural Engineering, Jawahar Lal Nehru Krishi Vishwa Vidyalaya (JLNKVV), Jabalpur, Madhya Pradesh in World Bank, 2015

(a) Result of agricutural university extension work – sunflower planted with only one set of plants per furrow, rather than the traditional two sets either side of the furrow. Higher yields given by allowing the sunflower adequate root and air/sunlight space. Naganadoddi village tanks, Raichur District.

(b) Improved variety of cabbage irrigated by drip irrigation, KCBTMP, Karnataka

Figure 8: Enhancing production through improved agronomic practices

Training in on-farm and in-field water management

Far more training and education is required in on-farm and in-field water management if water use efficiency and productivity is to be raised. Experience with the World Bank funded projects, with the exception of ADMIP in West Bengal, has shown that insufficient attention has been paid to practical, field-based training of WUA management, irrigators and government field staff.

Field-based demonstrations and practical exercises such as that shown in Figure 1 are required, together with physical models (Figure 7) and associated visual training materials to demonstrate the principles behind water movement and water uptake. In addition computer models such as BASCAD which model the flow of water over a field and into the soil can contribute significantly to visualizing and assisting understanding of the processes.

(a) A perspex-sided display cabinet for demonstrating infiltration rate in soil. The cabinet is filled with sand and water poured onto the top of the sand. The rate at which the water infiltrates into the sand and the depth to which a given depth of applied water penetrates can then be viewed.

(b) Two 1.5 litre plastic bottles (cut in half) are used to demonstrate infiltration, one filled with sand, the other with soil from a farmer's plot. Water is poured into both bottles at the same time and the different infiltration rates viewed. The bottles have holes in the bottom, as over-irrigation occurs the water flows out of the bottom of the bottle.

Figure 7: Use of models for demonstrating theoretical concepts

5.0 Conclusions and summary

This paper has highlighted the importance of surface irrigation in Indian irrigation and has cautioned against an over-reliance on pressurized irrigation systems comprising of drip and sprinkler irrigation to solve the water crisis. The paper has argued for a greater focus on improving surface irrigation through a range of measures extending from strengthening Water Users Associations to improving the way that individual farmers apply water to their fields.

From discussions with project and Department field staff the author has concluded that surface irrigation for smallholder irrigation systems has been overlooked and neglected by irrigation professionals, and that far greater attention needs to be paid to this crucial area. At the core is the need to study and understand farmers' behaviour at field level and then to develop a range of measures for improvement which fit with farmers' capability to implement them. As has been discussed simple field work by WUA management and farmers using relatively simple measures such as a single ring infiltrometer and a hand auger may play a significant role in reducing over-irrigation and improving application efficiency. A modest 20% improvement in application efficiency by even a fraction of the millions of irrigation farmers in India has the potential for making significant water savings.

It is clear that more education and training is required for farmers, but it is also clear that Water Resources Department and Agricultural Department staff need training and capacity building as current levels of understanding and knowledge of modern field practices has been found to be poor. A starting point for these improvements is the universities and colleges, particularly agricultural universities and colleges where greater emphasis needs to be placed on skilling young professionals in on-farm water management. Where they exist WALMIs also need to skill up and promote improved on-farm water management practices, and provide practical, field-based training to government department staff and water users.

Internationally funded projects can assist the process by focussing on performance management, using productivity of water as a key outcome indicator of project interventions in irrigation projects as well as ensuring that the project implementation team includes water management specialists and focussed activities to improve on-farm performance and productivity.

The proposed web-based continuing education programme on irrigation management being proposed by the International Commission on Irrigation and Drainage is to be welcomed, but will need to be recognised and supported by State Water Resources Departments as a valuable means to building their staff's capacity.

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