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Institutional Reform for Water Use Efficiency in Agriculture

International Best Practices and Policy Lessons for India

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ABSTRACT

What are the best methods in determining successful institutional reform for water use efficiency (WUE) in agriculture? Absolute water stress and relative water scarcity across economic sectors has increased the need for demand side management and improving water use efficiency in agriculture. This imperative is not unique to India but has driven attempts at reform in China, Mexico, Turkey, among many other countries. The complexity of dealing with agricultural water use efficiency and institutional reform requires collaboration and engagement with stakeholders at various levels of water management. There have been many debates on how to assess successful reform measures and determine which indicators are necessary to effectively monitor change. This paper outlines the alternative technical definitions of WUE, explains their weaknesses, and identifies comparative indicators that give a broad overview of the hydrological, agronomic, economic, financial, and environmental performance of irrigation systems. Thus, the paper sets up a framework that combines water availability, water use, and institutions and capacities as the three key indicators for comparing institutional reforms for WUE across countries. It explores these indicators using international case studies with varied institutional reform approaches and then defines the needs and priorities for India at different institutional levels. It recognises that this approach requires focusing on elements common to all systems such as water, land, and crop production. The paper ends by outlining three innovative institutional design options and policy recommendations focused on three issues: greater local participation in irrigation management, capacity building for water management decisions, and better understanding of hydrologic principles. None of the institutional options – shared management, joint management, and village-level management – is perfect, but each provides opportunities for a multidisciplinary, collaborative process to water management. The models are relevant not only for improving participatory irrigation management in India, but could also serve as the basis for more in depth cross-country research in future.

Keywords: Agricultural water use; China; India; institutional reform; Mexico; participatory irrigation management; Turkey; water use efficiency

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In 2010, Sachin was a development fellow at the Gujarat Institute of Development Research conducting policy research on India's watershed development program in southwest Gujarat in marginalised farming communities concerning community participation for water management and equity among tribes, women, castes, and other villagers. He also analysed multi-pattern links between natural resources and human well-being and provided enquiries examining the interface between poverty and climate change.

Sachin spent nine years at the U.S. Geological Survey (USGS) in Atlanta, Georgia and Austin, Texas primarily as a researcher on water resources issues including international transboundary water concerns, drought mitigation, technological advances in characterising hydrogeology and groundwater resource availability and quality. While with the USGS Sachin has travelled to various parts of the U.S. and the world conducting hydrologic research in India and United Arab Emirates. Furthermore, Sachin developed collaborations with the National Geophysics Research Institute in Hyderabad, International Boundary and Water Commission in the United States and the Symposium on the Application of Geophysics to Engineering and Environmental Problems.

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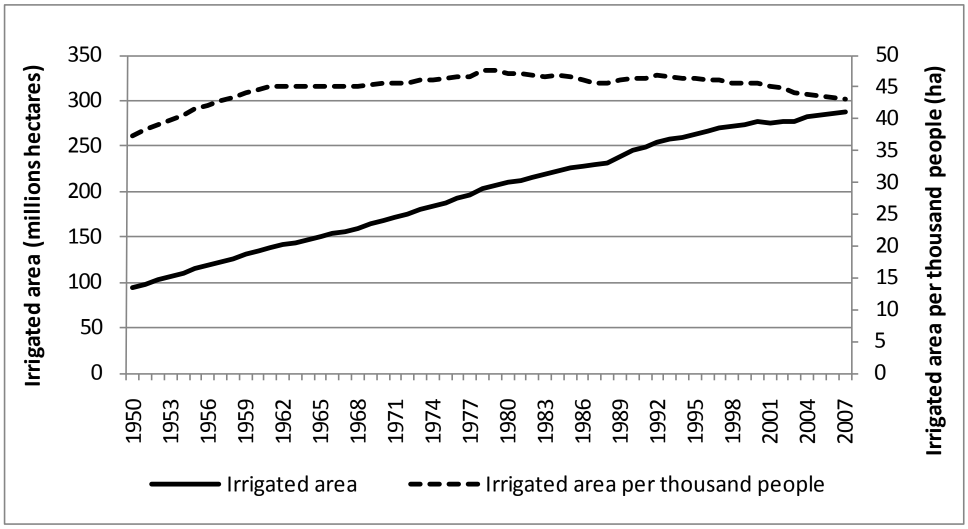
Introduction

Historically, most countries have tried to address the issue of water scarcity by developing new water sources under a supply management policy. Countries that have plentiful water resources can benefit from supply management to receive reliable amounts of water for irrigation. But increasing the amount of supply available is no longer feasible for most countries. Over the past decade, many countries are increasingly being confronted with the limits of their national water supply and are focusing on improving water use efficiency (WUE) as a way to maximise the potential of this exhaustible resource. Demand management is now the key policy imperative that has ignited the process of water institutional reform.

Moreover, according to the Intergovernmental Panel on Climate Change, shifts and variability in hydrological systems resulting from climate change will disproportionally affect the most vulnerable populations in the developing world. For agriculture this implies changes in the seasonal timing of rainfall and the higher incidence and severity of floods and droughts leading to difficulties in water resources management and, ultimately, water scarcity. Mitigation and adaptation approaches to maximising WUE in agriculture are likely to be more effective only if they are embedded in longer term strategies closely linked to agricultural and water policy reform by strengthening water management institutions.

In the developing world, agriculture typically accounts for the vast majority of water consumption by sector. In China, for example, agriculture consumes over 73 per cent of total water supplies, and in India the amount is even higher. Over the last 60 years there has been a massive increase in areas irrigated worldwide (figure 1). From 1950 to 2000 the irrigated area worldwide has increased at an annual rate of about 3.9 percent. This growth has only just kept pace with population growth, with the area irrigated per person changing relatively little from 37.3 hectares per 1,000 people in 1950 to 43 hectares per 1,000 people in 2007. In recent years the rate of development of irrigated areas has decreased as water availability has declined, all the while suitable sites for agriculture having been reduced due to industrial and urban development.

In many countries, significantly more water is delivered per unit area than is required leading to low WUE. Water deliveries rarely meet the quantity and timing required for maximising crop yields and leads to losses in productivity. The quantity of water used by crops is considerable. As a result, the volume of water handled by farmers for their crops must take into account the efficiency of water use as well as water distribution.



Source: Modified from EDI, 2009

Figure 1. Worldwide growth in irrigated area, 1950 to 2007

Over the last 25 years, different countries have implemented a range of strategies, sometimes concurrently, to adapt to the reduced availability of adequate water resources and improve unnecessary inefficiencies in water use in agriculture. Most countries have either adopted or considered demand-management policies such as water pricing in order to incentivise users to conserve water. Many agriculture experts advocate institutional reforms defining water as an economic good, rather than a public good, in order to allow market forces to affect demand. Other approaches that have become increasingly common in recent years include national governments allowing individual farmers greater participation in civic organisations, such as water user associations (WUAs) in order to influence agricultural and water management at the local level.

India is not new to water scarcity problems and debates over institutional reform strategies to increase production in agricultural areas. Despite its rapid development and urbanisation, industrial and domestic water users in India consume 9 percent and 7 percent respectively, while the agricultural sector consumes 84 percent of total supply. But India's dramatic development over the last two decades has created a rapidly expanding middle class whose water consumption needs will continue to increase domestic as well as industrial demand. This rapid growth, combined with limited water supply and the continuing importance of agriculture, illustrates the critical need for improved WUE in India.

Many states in India such as Andhra Pradesh, Madhya Pradesh, and Maharashtra, have made great strides in reforming its water institutions by adopting legislation to promote participatory irrigation management. Currently, the debate in India is realising the mechanism to negate the existing irrigation inefficiency and low crop yields and whether to reorient irrigation departments as a competent authority to provide technical support to farmers along different portions of the water delivery process. Understanding best practices from other countries will help build governance structures and understand key indicators that can assist in data-driven decision-making. Combining approaches to manage irrigation and improving WUE is being given preference as water managers and farmers alike realise that different conditions are necessary for maximising water use.

This paper seeks to identify successful water institutional reforms and best practices that have improved WUE in several countries including, but not limited to, China, Turkey and Mexico, in order to make recommendations for India's national, regional and local water institutions. The paper is structured around two critical questions:

1. What are the different institutional reforms that have been successful in other countries that India can learn from?
2. Can a multidisciplinary approach and multi stakeholder engagement process to water management improve WUE?

The paper is structured as follows. Part 1 provides descriptive and technical background on WUE and explores the complexities of understanding water use in different interest spectrums such as farmers, policymakers, and engineers. It also addresses water in the general context of the user—how various regions manage water resources either at the district, state, or federal level. A brief discussion on irrigation practices is given to provide insight to various technologies that are being implemented to improve WUE. This information culminates into the performance indicators that we researched and prioritised to develop an understanding of successful water management institutional reform.

Part 2 explains the methodology used to assess successful water management institutional reform on the basis of three main sources, or "baskets," of water use efficiency, namely water availability, water use, and institutions and capacity. Part 3 consists of case studies on water management institutional reforms primarily in China, Mexico, and Turkey as well as other countries, and their resulting WUE improvements. Part 4 analyses water resource development in agriculture in India over the last 20 years setting the stage for best practices for reform for India. It introduces innovative institutional reforms that could be implemented using best practices from countries in the selected case studies. Part 4 also synthesises these best practices and provides policy recommendations relevant for India's case.

This paper does not claim to present a single solution as a panacea to the wide range of concerns in maximising WUE through institutional reform. It does, however, point to successful reform from other countries and the institutional design choices. Furthermore, the paper addresses the need for a more scientific approach to understanding WUE, enhancing communication among sectors, and delivering more data-driven policy decisions. Our aim is to provide this analysis that would help policymakers explicitly confront the various dimensions of WUE, different institutional design options, and understand the connection between water availability (hydrology), water use, and institutional capacity.

Key Discussions in the Literature

The social and economic benefits of maximising water use efficiency have been extensively researched over the past 30 years. Saleth and Dinar (2005) point to a vast theoretical literature elaborating the gains possible from institutional changes in the water sector. While the literature in a general institutional context includes the works of Olson (1971), Bromley (1989), and North (1990), that in the water institution context covers the important works by Frederikson (1992), Le Moigne, et al., (1994), and Picciotto (1995). There are also few recent studies which try to quantify the potential gain from changes in a particular segment of water institutions like water markets, inter-regional transfers, and water quality institutions (Vaux and Howitt, 1984; Dinar and Latey, 1991; Zilberman, et al., 1998; Howitt, 1994). Much of this literature expounds on the evolution of the management structure of various countries and the relationship between government power and water institutions.

Blomquist et al. (2005) point to a number of policy recommendations, particularly for improving WUE, which have been reiterated over several decades in the professional literature (Ingram *et al.,* 1984; Lord, 1984; El-Ashry and Gibbons, 1986; Reisner and Bates, 1990; Livingston, 1993; Anderson and Snyder, 1997; Haddad, 2000). Scientific studies on WUE can also be found with topics ranging from crop type analysis to infrastructure design literature (Fang et a., 2010; Deng et al., 2006; Bos et al., 2005). Although considerable research has been done on WUE over the past century, much of the work resulted in empirical solutions that were inconclusive or inconsistent when applied across different geographies. For example, plant WUE was a topic for early scientific discussion (Briggs and Shantz, 1913). Knowledge of the factors influencing crop WUE and a hope to improve the efficiency has continued to be an objective in many modern investigations.

Many argue that efficiency may be obtained by optimising the use of water and infrastructure through active participation by users with a sense of social responsibility (Arreguin, 1991). Based on the many interpretations of institutional reform and linkages to WUE, the examination of WUE requires a multidisciplinary approach. Expanding the literature on how we think about the link between WUE and institutional reform requires research and analysis beyond irrigation performance. In addition to irrigation factors, social, economic and environmental factors must all be considered.

Much of the research in the literature proposes numerous indicators to measure WUE. In particular both Rao (1993) and Bos et al. (2005) focus much of their work in irrigation performance assessment by analysing the internal processes of irrigation systems pin-pointing engineering methods and capable technologies for WUE. The International Water Management Institute (IWMI) states that comparative performance indicators such as rainfall or technology capacity make it possible to see how well irrigated agriculture is performing in a system, basin or national scale. IWMI and others (Molden et al., 1998; Klozen and Restrepo, 1998) argue that comparative indicators give a broad overview of the hydrological, agronomic, economic, financial, and environmental performance of irrigation systems to help drive decisions on how to improve WUE. This approach most appropriately relates to the aim of this paper: focusing on elements common to all systems such as water, land and crop production.

There have been many studies using different indicators for the evaluation of irrigation performance leading to WUE in Central and South America (Klozen and Restrepo, 1998). Comparative indicators defined as "relative water supply", "relative irrigation supply", "water delivery capacity", and "production per cropped area" helped define successful reform for areas such as Alto Rio Lerma, Mexico and Peru. Furthermore, Scheumann and ul-Hassan (2001) contend that the ownership of land impacts fee payment and financing services. In Turkey, for example, many farmers rent out their land to others. Only registered landowners are liable to pay fees, which they collect from tenant farmers. In their research, it was found that some WUAs have low fee collection rates in the years when services were provided, due to the high percentage of sharecroppers in Turkey.

These indicators have proved to be useful as they provide important information about the performance of various water management institutions where the indicators were applied. However, many of the indicators mentioned above have shown some limitations to their usefulness and applicability. These limitations include:

- Most authors propose to use different indicators or to use different methodologies to measure the same indicator. Generally, these indicators address how a certain aspect of the institution is performing, but do not provide information on what the wider hydrological or environmental impacts are that may have led to a successful or unsuccessful institution.
- Many of the performance assessments described in literature were done in the context of intensive research programmes, often to test new indicators introduced by researchers, rather than proposed by water managers. As a result, little is known about how water managers perceive the usefulness of these performance indicators for daily water management or day-to-day monitoring.
- Measurement of many of these indicators requires comprehensive data collection. Monitoring plans or systems are typically not set up to collect these required data. As a consequence, applying these indicators requires additional staff, skills, and equipment that are generally not available within irrigation systems or are hard to obtain.

In order to evaluate water institutional success, hydrologic and climatic conditions, water availability, and characterisation of water use have to be taken into account, along with institutional characteristics relevant for the local conditions. Table 1 lays out common indicators (some of which were chosen for this study) and their availability in the breadth of the literature. Metrics such as effective rainfall, groundwater withdrawal, and relative water availability are found in scientific literature used to conduct hydrologic modelling for water availability in rural and urban areas. Other indicators such as fee collection, financial sustainability, and stakeholder capacity are used when measuring successful farmer participation in irrigation management. We believe that combining these indicators improve upon and complement the methods found in literature to help determine improvements in WUE triggered by institutional reform.

Table 1. Common indicators to evaluate water use efficiency found in the literature.

Performance indicator	Similar or proxy indicator used in case studies	Author(s)	Country
Effective rainfall	Annual precipitation	Deng et al. (2006); Moret et al. (2005); Brekke et al. (2009)	China, Spain, United States
Groundwater withdrawal	Groundwater use	IWMI (2002); Brekke et al. (2009)	Mexico, United States
Relative water availability	Soil water availability, relative water supply	Fang et al. (2010); Friedler (2000); IWMI (2002)	China, India, Israel, Mexico
Crop type		Deng et al. (2006); Wijesekera and Wickramaarachchi (2003)	Chile, China, Sri Lanka, Turkey
Percent of available land irrigated	Irrigation intensity	Molden et al. (1998); Yercan et al. (2009)	Turkey
Water delivery capacity	Water delivery loss	Fang et al. (2010); IWMI (2002); Vos (2005)	China; Mexico; Peru
Irrigation technology or system in use	Irrigation scheduling	Ortega et al. (2005)	Spain, United States
Infrastructure maintenance	Operations and maintenance expenditures	Huang et al. (2010)	China
Fee collection	Cost recovery, fee collection rate, fee collection efficiency	Huang et al. (2010); Yercan et al. (2009)	China, Philippines, Turkey
Financial sustainability	Cost recovery, financial self sufficiency	IWMI (2002); Kloezen and Garces-Restrepo (2002); Yercan et al. (2004; 2009)	Mexico; Turkey
Crop production per unit water supply	Output per unit irrigation supply, Crop production surplus/deficit as a percentage of consumption	Amarasinghe et al, (2004); Sakthivadivel et al. (1993)	Columbia, India, Mexico, Morocco, Sri Lanka, Turkey, USA
Technology capacity	On-farm irrigation system	Ortega et al. (2005)	Spain
Stakeholder capacity	Personnel intensity, participation	Stanghellini (2000); Blomquist et al. (2004); Yercan et al. (2009)	Italy, Turkey, United States

PART 1: WATER USE EFFICIENCY IN PERSPECTIVE

Why Worry about Water Use Efficiency?

World agriculture faces an enormous challenge over the next 40 years: to produce almost 50 percent more food through 2030 and double production by 2050. This will have to be achieved with less water due to pressure from growing urbanisation, industrialisation, and climate change. The growing scarcity and rising cost of water have led to the realisation that water has to be allocated and used more efficiently. It will be important for farmers to receive the right signals to increase water use efficiency and improve agricultural water management, especially as agriculture is the major user of water in most countries.

WUE is widely used as a metric for evaluating water management policy success, analysing the water saving performance of irrigation systems, and comparing different irrigation systems. The importance of WUE varies across regions and nations as well as through time. Geographically, water availability will determine the manner in which water use patterns develop. For example, with all things being equal, arid and semi-arid regions (western India) require a greater efficiency of water use than humid regions (southern India).

Future policy decisions to address the management of water resources in agriculture will be influenced by many diverse drivers. In developing countries such as India, crop management, technology, climate variability, and energy costs for pumping water are particularly important. This is why sustainable management of water resources in agriculture requires a multidisciplinary approach that incorporates many disciplines of study to move towards more efficient management and use of water. In general, a comprehensive approach to resolving the inefficiencies of water use and the institutional reform processes that will govern them require policymakers, scientists, engineers, and farmers to:

- Recognise the complexity and diversity of water resource management in agriculture as it relates to varying regional and national water resource supply and accompanying WUE practices.
- Strengthen institutions for water management in agriculture.
- Improve policy integration and coherence between agriculture, hydrology, and engineering.
- Address knowledge and information deficiencies on all levels to better guide water resource management.

Defining Water Use Efficiency

Many researchers have proposed different criteria for defining and evaluating water use efficiency. Farmers, engineers, hydrologists, and policymakers analyse and interpret the importance of WUE differently and, therefore, use multiple definitions to calculate WUE. Defining WUE for irrigation is complex because the scale of importance for the water resource shifts to the broader hydrology, watershed, irrigation district, project scale, or policy, and the water components may not be so precisely defined. As a result, calculating WUE becomes more qualitative and terms such as “reasonable”, “beneficial”, or “recoverable” are used (Howell, 2001).

At a basic level, WUE is generally defined (Viets, 1962) as

$$\text{WUE} = \frac{\textit{Volume of water utilised}}{\textit{Volume of water extracted from the supply source}}$$

WUE in irrigation has three components where the total efficiency of water use in irrigation (Hamdy, 2007) is expressed as E_i:

$$E_i = E_s + E_c + E_u$$

where

E_s is storage coefficient: the volume diverted for irrigation & the volume entering a storage reservoir

E_c is conveyance efficiency: volume delivered to irrigation plots & the volume diverted from the supply

E_u is irrigation efficiency: volume used by plants throughout the evapotranspiration process

In sum, these components encompass: losses in the distribution system due to leakage and evaporation; losses during water application to the field are due to wind, evaporation, and runoff; and losses from the soil due to excess water applied beyond what the crop uses.

Although useful in many analyses, this basic definition of WUE does not take into account the role of the volume of evapotranspiration. To consistently discriminate the role that irrigation has in WUE, evapotranspiration must be added into the calculations (Bos, 1985):

$$\mathbf{ET}_{\mathbf{WUE}} = \frac{(Y_i - Y_d)}{(ET_i - ET_d)}$$

$$\mathbf{I}_{\mathbf{WUE}} = \frac{(Y_i - Y_d)}{I_i}$$

where

ET_{WUE} is the WUE taking evapotranspiration into account;

I_{WUE} is the WUE taking irrigation into account;

Y_i is the yield under all climate conditions;

ET_i is the evapotranspiration for irrigation level i;

Y_d is the yield under localised dry or wet conditions;

ET_d is the evapotranspiration for an equivalent dryland or rainfed only plot;

I_i is the amount of irrigation applied for irrigation level i;

The advantage of using this definition of WUE is that it separates arid (western Mexico) versus wet (western Turkey) areas. For example, in most arid areas such as the Northern Plains of China, Y_d would be zero or very small; however, ET_d could be much greater than zero and variable depending on the agricultural practices.

In semi-arid and rainfed areas such as southern Vietnam and Laos, determining Y_d is a little more complex. Agronomic practices (for example modern drip irrigation for lettuce versus flood irrigation for rice) and differences in irrigation management differ substantially between dryland and/or rainfed areas. Thus, results that are quite different might be obtained for $Y_{d\text{ and}}$ ET_d. As a result, a benchmark WUE (WUE_b) is used by many irrigation practitioners (Howell, 2001) defined as

$$WUE_b = \frac{\textit{Crop yield (usually economic yield)}}{(P_e + I + SW)}$$

where

P_e is effective rainfall;

I is irrigation applied;

SW is soil water depletion from the root zone during the growing season;

According to Howell et al (1990) and Cooper et al. (1987), agriculture managers typically use this for specific regions (within a basin or watershed level) and to identify differences between irrigation methods and irrigation management.

Other definitions of WUE focus in areas where there is considerably more plant cover and reliable rainfall, such as western Chile and parts of South Africa. In this case the most commonly used efficiency terms are:

Ea, application efficiency;

*Es, s*torage efficiency*;*

U, coefficient of uniformity;

Nevertheless, none of these terms alone can fully characterise the effectiveness or performance of applying water for irrigation. Application efficiency is defined as the water stored in the soil root zone/water delivered to the field. Application efficiency *(Ea)* describes only the fraction of applied water that could be used by plants. It is mainly concerned with the efficiency with which water is being utilised. However, it does not provide information regarding adequacy and uniformity of irrigation.

The storage efficiency (*Es)* is defined as the water stored in the soil root zone/water needed in the crop root zone. This is a measure of the adequacy of wetting in the crop root zone and is mainly concerned with the crop yield effectiveness. But, it does not account for the water losses beyond the root zone. As a result, there actually may be a gain in water to an aquifer below the root zone, but such measurements are not taken into account with this measurement calculation. Therefore, semi-arid and arid regions, such as the southwestern United States and the western state of Gujarat, cannot consistently use this method to determine WUE and consistently compare management techniques between localised or global regions.

An innovative approach to measuring WUE in the field is based on research conducted by Cooper et al (1987) and Gregory (1990). This definition takes into account the pre-conditions of crops before precipitation and post-rainfall (volume of surface runoff). Runoff can be an important component in arid regions where crop seasons are short and rainfall is limited. (Also note that in India, very little attention is paid to measuring rainwater use, so measuring WUE based on rainfall runoff and utilisation can fill existing data gaps.)

$$WUE = \frac{(HI \times DM)}{\left\{T(1 - WC)\left[1 + \frac{E}{(P + I + SW - D - Q - E)}\right]\right\}}$$

where

HI is the harvest index (dry yield per unit dry matter);

DM is dry matter (above ground dry matter and roots);

T is transpiration;

WC is the standard water content used to express the economic yield;

E is soil water evaporation;

P is precipitation;

I is irrigation;

SW is soil water depletion from the root zone;

D is deep percolation beneath the root zone;

Q is surface runoff;

From an engineering perspective, The American Society of Civil Engineer's Irrigation and Drainage Division suggested a new application efficiency term, *irrigation sagacity (IS):*

$$IS = \frac{\text{Irrigation Water Beneficially and Reasonably Used}}{\text{Irrigation Water Applied}}$$

Beneficial uses include such items as crop evapotranspiration, leaching, germination, temperature and humidity control, and soil preparation. *Reasonable uses* include water needed to maintain drainage water quality, some deep percolation due to nonuniformity and uncertainties in salt management, and various losses that may not be economical to avoid.

Using irrigation sagacity provides an interesting approach for system design and determines a more realistic efficiency concept for evaluating irrigation systems because it includes beneficial and reasonable uses in addition to crop evapotranspiration. However, irrigation sagacity is typically a metric used by civil engineers to determine the viability of water development projects such as the construction of reservoirs.

Irrigators, farmers, engineers, hydrologists, and policymakers have struggled with the classical irrigation efficiency concepts and have attempted to untangle such problems as:

- How to deal with application uniformity, effective rainfall, and estimating actual crop evapotranspiration;
- Other than evapotranspiration what is a legitimate variable to measure natural loss;
- How to deal with practical values for conveyance losses (poor infrastructure), application uniformities, meeting evapotranspiration potentials, and irrigation frequency and scheduling.

Irrigation Technology and Practices

In traditional surface irrigation methods there is substantial water loss due to evaporation and runoff. Innovative irrigation technologies are increasingly seen as a means of addressing water wastage, growing competition over scarce water resources in agriculture, and improving WUE.

Technical awareness of these irrigation technologies to improve WUE are slowly being implemented in developing countries. Typical solutions to overcome water loss and increase crop yield include (2030 Water Resources Group, 2009):

- Drip irrigation systems to reduce water application inefficiencies by 30 percent;
- Sprinkler irrigation to provide gross water savings of 12 to 15 percent from reduced evapotranspiration;
- Agriculture productivity measures such as improved fertilizer balance to increase yields in rained cropping areas by 10 percent;
- Eliminating till farming to increase gross water savings by 12 percent;
- Utilisation of best available seed development to raise crop productivity;
- Alternative cropping patterns to help achieve more revenue per water drop.

Over the past decade, India has adopted the use of drip and sprinkler irrigation methods considerably decreasing losses. Among all of the irrigation methods, drip irrigation (or micro-irrigation) technology is the most efficient and is used for a wide variety of crops, such as vegetables, flowers, and plantation crops. In drip irrigation, water is applied near the plant root through emitters or drippers, on or below the soil surface, at a low rate varying from 2 to 20 liters per hour. The soil moisture is kept at an optimum level with frequent irrigations. Drip irrigation results in a very high water application efficiency of about 90 to 95 percent (Government of India, 2011).

In Maharastra, farmers have invested in drip irrigation systems for grapes, potatoes, and other vegetables assuring them of more efficient water use and sustainable water supplies throughout a cropping period. Today about 4,100 hectares in Maharastra are irrigated with drip irrigation systems

(Government of India, 2011). Furthermore, more traditional sprinkler irrigation systems are being adopted in Haryana, Rajasthan, Uttar Pradesh, Karnataka, and Gujarat. The use of sprinkler irrigation saves about 56 percent of water for winter crops such as bajra and jowar and about 30 percent for cotton (Kumar et al., 2005). In general, the use of drip irrigation and sprinkler technologies in India has resulted in a significant yield improvement over traditional practices such as flood irrigation (table 2) depending on crop type.

Table 2. Increased crop yield due to drip and sprinkler technologies compared to conventional irrigation methods such as flood irrigation

	Change in yield from new irrigation technology (total hectares)		
Irrigation technology	Banana	Groundnut	Cotton
Low-cost drip	+14.2	-	+0.7
Micro-tube drip	-	+0.4	+0.5
Conventional drip	+18.1	-	+0.9
Micro-sprinklers	-	+0.7	-
Conventional sprinklers	-	+0.5	-

Source: Adapted from Varma et al., 2006

As in India, in Mediterranean countries such as Turkey both the application efficiency and storage efficiency are generally low. On average, only 45 percent of the water used for irrigation actually reaches the crops (Hamdy, 2007). Based on the scale of the irrigation scheme, water losses vary between 5 and 50 percent. Table 3 shows the irrigation efficiency percentage of typical irrigation schemes found in the Mediterranean region. Higher efficiency percentages correspond to better utilisation of water by crops.

Table 3. Typical project irrigation efficiencies in agricultural regions of the Mediterranean

Irrigation System	Country	Effciency Percentage
Traditional open canal system (manual control)	Turkey	50
Open canal systems with hydraulic control and surface irrigation	Morocco	60
Open canal systems with manual control, on-farm storage and sprinkler/drip irrigation	Jordan	70
Open canal systems with hydraulic control, buffer or on-farm storage and sprinkler/drip	Turkey	70
Pipe conveyance systems with sprinkler/drip	Cyprus	70
Groundwater irrigation: lined channels and on-farm surface	Turkey	50
Groundwater irrigation: pipe systems and on-farm sprinkler/drip	Turkey	70

Source: Adapted from Hamdy, 2007

Water Use Efficiency Performance Indicators

As is evident from the technical definitions of WUE, there is no "one size fits all" solution to determining WUE. With this technical conundrum in mind, we develop a framework to identify key performance indicators for measuring success in projects aimed at improving WUE. Hence, we use indicators grouped into three categories or "baskets" to offer supporting evidence to our hypotheses and the technical solutions identified above. These baskets include: water availability; water use; and institutions and capacities.

The indicators applied in this study are typically used in different social, hydrologic, and engineering, research studies to determine:

1. Success or failure of water management institutional reform on a localised or regional scale;
2. Modelling of water availability in aquifers and rivers based on agricultural practices or engineering structures;
3. Successful participatory irrigation management and determining the sustainability of water management at the farm-level.

Additionally, 0rganisations such as the IWMI, International Association of Hydrogeologists, and the U.S. Army Corps of Engineers frequently use many of these indicators in various technical studies ranging from analysing water policy to evaluating dam control.

Table 4. Indicators (in order of importance) organised into baskets to measure performance of institutional water management and water use efficiency in agriculture.

Basket	Performance indicator	Definition	Notes
Water Availability	Effective Rainfall	Volume of rainwater available / Actual amount of rainfall	
	Relative Water Availability	Total water supply (irrigation + total rainfall) / Total crop demand at field level	Variation of the RWS at the main canal intake and at tertiary intakes during the season indicates the level of reliability of water supply and delivery
	Groundwater withdrawal		The volume of groundwater that is withdrawn from a well.
Water Use Performance (Irrigation practices)	Irrigable land or Crop production per unit water delivered	Total crop production / Volume of water delivered (to tertiary unit or field)	This is an increasingly important indicator as relative water availability declines over time. Need to be careful where there is mixed cropping.
	Relative Water Supply (RWS)	Volume of irrigation water supplied / Volume of irrigation water demand	Measured at main canal intake and each tertiary unit intake. Target value = 1.0, less than 1.0 indicates water shortage
	Crop type	Crop to be produced	Crop types differ depending upon region, climate, water availability, and technology.
	Irrigation technology or system in use	Describes the level of technology used: conventional versus new micro-irrigation technologies	Important to determine if the technology is inefficienct or outdated based on the entire hydrologic system.
	Delivery Performance Ratio (DPR)	Volume of irrigation water supplied / Target volume of irrigation water supply	Measured at main canal intake and each tertiary unit. If there is a water shortage the target supply may be less than the actual irrigation water demand.
Institutions and capacities	Financial sustainability	Water charges / Cost of operation and maintenance	Is also referred to as a percentage where the cost of operation and maintenance of a canal is a function of water charges
	Water delivery capacity		Addresses whether the system has been designed and constructed in such a way as to be able to meet the peak water demand in a particular period.
	Fee Collection	Ratio of irrigation fees to maintenance expenditure	Consistency of fee collection for irrigation management, operation, and maintenance
	Infrastructure maintenance	Consistency or ability of institution to maintain irrigation and water infrastructure	Ratio of maintenance expenditure to required cost of operation and maintenance
	Timeliness of Irrigation Water Delivery	Actual date/time of irrigation water delivery / Planned/Required date/time of irrigation water delivery	Compares the actual date and time of delivery (planned in the rotation or requested by the farmer) compared to the actual delivery date and time.

At this stage, we hypothesize that through the use of specific indicators, we would beable to document and compare key performance attributes of efficient water use and successful water management institutions. If so, it should be possible to compare performance across water management institutions in a number of settings, including relative performance of institutions in India, and to offer lessons for institutional reform and improving performance.

Specifically, performance is assessed for a variety of reasons: to assess the general structure and performance of water management institutional systems, to diagnose constraints on WUE, and to compare the performance of water management institutions with others and develop best practices.

In order to measure success in projects aimed at increasing WUE, the framework is developed as a best practices "categorical" model. Best practices models vary widely based on the geography, agroclimatic conditions, irrigation practices, and institutional strength. A relative comparison allows us to examine how well a country is performing for measuring WUE (successful institutional reform) in relation to others. The methodology of this study in explained in further detail in the next section.

Based on analyses conducted in the literature, the most salient indicator from each basket includes effective rainfall (water availability basket), irrigable land (water use basket), and financial sustainability of the institution (institutional capacity basket). Therefore, our hypotheses for measuring success in water management institutions are:

1. The salient indicators that allow us to distinguish between WUE performance across geographies and climatic regions are effective rainfall, relative water availability, irrigable land, and institutional financial sustainability.
2. Secondary and tertiary level institutions such as distributary stations and water user associations should be delineated along hydrologic boundaries such as minor watersheds, distributary and/or branch canal systems.
3. Scientific and technical data, management, and dessemination standards are necessary to improve WUE beyond basic administrative institutional reform.

PART 2: METHODOLOGY

Ultimately the purpose of comparing country cases and their institutional design is to understand whether the aforementioned indicators are appropriate for determining which institutional reform measures are delivering on promised benefits. Thus we identify studies from a larger database of cases that are used to showcase significant successes or failures. The choice of cases will help to illustrate the complexities between water availability and use, institutional innovation, and capacity to deliver. Pulled together, the insights from the cases offer lessons for appropriate policy and institutional design to complement the economic analysis and research of technical solutions.

Research Methods

This report comprises data from studies conducted in thirty countries. From these, three primary countries were chosen: China, Turkey, and Mexico. Although the comparisons are focused on these three sample countries, the experience from other countries and regions are used to reinforce some points in a few relevant contexts. We focused our report on these countries due to their climatic, hydrologic, and agronomic similarities to India. Since the sample countries cover different continents, historical backgrounds, political systems, development stages, and levels of water scarcity, they represent well recently observed institutional changes and water sector reforms in terms of their effectiveness in comparison to India. The role of these case studies is to provide successful scenarios and reform measures that have maximised WUE in other countries that could help formulate successful scenarios in India. In cases where both agricultural and management practices differ in dry and humid areas, for example, comparisons and best practice results will differ in each country and therefore may be appropriate only in certain regions of India that have vastly different WUE and institutional problems.

In order to establish an appropriate range of values for interpretation from these case studies, a core group of performance indicators are separated into three categories or “baskets”. These indicators help us sort through successful best practices and options for institutional reform. These sources of success for reform are described as “baskets” since they each contain multiple indicators. The baskets were created to easily compare practices and conditions within specific agro-climatic zones for hydrologic, physical, and management indicators. Hence, we use multiple indicators contained within the three baskets to offer supporting evidence to our hypotheses and the technical solutions identified above.

Most of the data used for the analysis are survey data derived from official statistics and measurements or collected and compiled by collaborating scientists and 0rganisations working in different countries. Furthermore, we collated data by conducting a literature search, obtaining data from other institutions and structured primary research. This included desktop literature surveys, data mining from literature and research institutions such as International Finance Commission (IFC), World Bank, International Water Management Institute (IWMI) and other water policy research 0rganisations.

Analyses conducted by these scientific and policy institutions used many of the same indicators we have proposed in this study. We found that performance was assessed in a variety of ways: to improve system operations, to assess impacts of reform, to diagnose constraints, and to compare the performance of one system to another. These indicators fall into the “institutions and capacity” basket (see below) where the performance measurement is based solely on the performance activity within an institution and not on the natural hydrologic system. For other indicators such as those categorised under “water availability analysis”, we found that runoff was seldom taken into account primarily because it is a difficult parameter to measure without knowing the effective rainfall. As in most cases that involve the complexities of hydrology, water management institutions cannot be based on institutional performance alone; hydrologic indicators such as water availability and irrigable land are some of the links to improving WUE.

Water Availability Analysis

The viability of arrangements for irrigation management (new institutions) under the condition of market-oriented reform also depends heavily on the absolute availability of water. Water availability can influence not only the type of irrigation institution but also the institutional viability, such as participatory irrigation management systems or other formal systems. Absolute water availability is determined by climate, water quality, agro-ecological characteristics (soil type, water retention), and catchment conditions such as runoff, storage and groundwater recharge. Hence the indicators we have chosen are effective rainfall, groundwater withdrawal, and relative water availability.

Water Use Analysis

Furthermore, to enhance the analysis on WUE best practices and policymaking, the relative water availability must also be considered. Relative water availability is determined by the level of regional and local distribution of irrigation demand *in relation to* water availability. Irrigation demand is determined by water management activities or changing water use patterns under certain conditions. Additionally, demand is influenced by irrigation technology and social and economic requirements of water use. Within these set of factors, managers and water users apply different water management policy actions to alleviate the level of water use. In order to capture the variability of water use under different irrigation practices, crop type, percentage of irrigable land, water delivery capacity, and irrigation technology are used as indicators.

Institutions and Capacity

There is a need to understand the structure of the local water users' institutions that have emerged and how they differ from existing formal institutions. In general, the analysis includes comparisons of the institutions themselves. This includes recently implemented institutional reform program dealing with planned intervention strategies aiming to reshape the management of water resources for agricultural use. This part of the analysis examines existing institutions, existing institutions that have been transformed, as well as institutions that were newly planned and created generally (but not necessarily) with new actors involved. Planned intervention refers to *formal* design and implementation of better or new institutions. We use the following indicators to deconstruct institutional reform processes to identify general guidelines for conditions that deliver the highest efficiency levels: infrastructure maintenance, fee collection, financial sustainability, technology access, technology capacity, and stakeholder capacity.

The major limitation of using these indicators is the uncertainty involved in many of the estimates. Two major uncertainties exist: uncertainties in the source of data, and uncertainties in the estimates. All of the data comes from secondary sources, not directly measured by the researchers. There is a wide variety in the quality of data obtained from these sources. Since many of the indicators we suggested in our hypothesis were not available, we decided to focus on cases that have similar starting points. These findings should serve as the basis for developing larger scale research projects and help establish contacts with regional agencies and WUAs to access better data.

Approaches to Country Case Studies

This report focuses on institutional reforms that have been successful. The main criteria for selecting countries for this study was that the country demonstrated a significant level of improvement in WUE during the past twenty-five years in ways that are financially and economically sustainable. The three countries that were selected for the study include: China, Mexico, and Turkey with some examples from other countries such as Vietnam, Israel, and Australia throught out the report. All of these countries had high economic growth during the period, and this growth correlates with successful institutional reform leading to higher WUE in agriculture. The countries with highest levels of growth and highest improvement in WUE over the last 25 years are Mexico and Turkey. The countries with successful institutional reforms do not follow one institutional model, indicating that reform is not impeded by different ways of maximising WUE.

In this study, we have given importance to three types of institutional reform. The first type involves central and/or regional water institutional reform. Examples of countries following this reform model include Mexico, Turkey, and certain regions in China. A second common path to institutional reform is participatory irrigation management (PIM), which includes the establishment of water user associations

(WUAs). Countries that exemplify success under this category include China, Mexico, Turkey, Vietnam, and Bangladesh. Australia, a developed country, also had a partial PIM programme prior to creating successful water management institutions. Additionally, there is discussion of the implementation of the contracting water management system primarily used in China. China has used contracting in various forms over the past 20 years, and has unique measures in place to incentivise both water managers and farmers to increase WUE.

Could programmes that have not been successful also hold lessons for water management institutional reforms? There are plenty of examples of reforms with problems or reforms that have not yet been developed. Many African countries provide examples of reforms that have had significant problems because of unsuccessful national development models of central water planning. Many of the lessons learned from these case studies are applicable to India's case where there has been minimal water institutional reform. However, the main lessons are in successful reform measures and such lessons can be applied to countries such as India, where there is renewed attention to reforming water resource institutions (Burton et al, 2011).

PART 3: CASE STUDIES

The world water crisis is one of governance –how is water managed at different institutional levels, which actors are managing water resources, and who gets access to water? This section provides case studies of increasing WUE resulting from various water management institutional reforms in three countries: (1) China, (2) Turkey, and (3) Mexico with comments and examples about reforms in other countries with similar conditions to India. These countries were chosen based on similarities on at least four out of the five following conditions: socioeconomic conditions, climatic conditions, extent of development, water institution governance structures, and percentage of land-based agriculture. Since institutional reform is complex, the country-specific review attempted below is brief, focusing on key features of existing institutional reforms and arrangements in successful water institutions.

China

In some regions of China, such as in Huebei Province, irrigation management is organised based on both political and hydrologic boundaries. Irrigation administrative water management bureaus, for instance, depend upon the size of the area to be served and access to the primary water source. For example, a provincial water resources bureau will bypass the irrigation management bureau if a township is large enough to warrant a county water resources bureau for its water management and partner with a WUA on a village level (Wu and McKay, 2005). If villages are smaller and in areas where their water source are further away (over 30 miles), then the irrigation administration bureau administers control over the management with the canal offices and management stations located at secondary canal lines for efficient management.

The reform measures designed by many irrigation administration bureaus include awarding contracts for water management. Some contracts are established mainly for the operation and maintenance of the tertiary system while others include an obligation to invest in rehabilitation and construction (Johnson et al., 2004). Contractors helped improve WUE by maximising the irrigable land for crop production in China and gain incentives for reducing water use beyond a set quantity. Wang et al. (2005) showed that, holding other factors constant, in villages in which contracting managers were provided with incentives to save water, water use declined by about 40 percent. The research also showed that water savings were achieved without negatively affecting crop yields or income.

The performance of contracting in China has been evaluated by measures including fee collection (financial sustainability), water use, and crop production per unit available water –indicators that are necessary to measure successful institutional reform. In India, contracting could complement existing structures in place established under PIM if clearly defined roles and responsibilities among WUA management and irrigation agency personnel are set.

A different type of contracting framework was put into place during institutional reform in the Philippines. Under the terms of PIM reform, farmers have a choice of (1) a maintenance contract with the National Water Commission, (2) a contract covering maintenance and irrigation service fee collection, or (3) a contract covering maintenance, fee collection, and full operations of the relevant canal (Groenfeldt, 1997). This system provides farmers a little more stability and financial sustainability by not assuming all irrigation management duties and, instead, sets up the institutional infrastructure on stronger footing.

In other parts of China such as the Heihe River Basin, the main river (Heihe River) flows across three provinces that have major differences in economic structure and water use practices. In these provinces, water conflicts are rampant and make basin management complicated (Chen et al, 2005). In these cases, the administrative duties for the central and regional authorities are constrained in their capacity to coordinate water use effectively and the focus of reform here was on WUAs to act as arbitrators for conflict management. Management institutions delineated along hydrologic boundaries are necessary for distributing responsibilities for all stakeholders. As specified in our earlier hypothesis, secondary and tertiary level institutions formed along hydrologic units such as basins or smaller watersheds, allow for fewer conflicts and reduce the duplication of effort amongst administrative resources.

An important and often overlooked component to China's institutional reform is transparency of information under WUAs. According to Huang et al. (2010), management under WUAs is more transparent than under contracting. In northern China, farmers benefited tremendously by knowing the total amount of water fees collected, the volume of water actually delivered and the actual area irrigated. Farmers in India could benefit from this type of information sharing, thereby increasing stakeholder capacity, farmer participation, and strengthening water institutional structures.

Mexico

In Mexico, the National Water Commission (CNA) developed a system of coordinated responsibility with WUAs to improve system performance and ensure financial self-sufficiency and limit its responsibilities to enforcing regulation and managing dams and head works (Kloezen, 2002). Decentralised tasks were given to regional administrations to promote and strengthen river basin councils and coordinate water planning and reservoir operation. Reform in Mexico focused on WUA financial sustainability, stakeholder capacity, and infrastructure maintenance primarily because the transfer of ownership meant that the technical, administrative, financial, and operational duties were independent management functions (Groenfeldt, 1997). As a result, indicators found in literature to measure performance are mainly focused on institutional and capacity indicators such as financial self-sufficiency. Although not provided in our original list of indicators, Kloezen and Garces-Restrepo (1998), use gross return on investment as a component of financial sustainability (gross value of crop production divided by the cost of irrigation infrastructure) where the cost of an irrigation distribution system refers to the estimated current cost of construction for an equivalent delivery system.

Regional administrations, in turn, created the boundaries of the these modules based upon hydrologic considerations so water could be delivered to an area more easily and efficiently and, where possible, fit within farmers' existing irrigable land (Kloezen, 2002). Additionally, in order to have an economically viable management size with relatively low fixed overhead costs, the sizes of the hydrologic management areas are relatively large (macro watersheds scale), ranging in size from 1,500 hectares to 50,000 hectares, each managed by an individual WUA – a reform measure that made WUAs more effective and less prone to conflict.

A vital reform measure in Mexico placed WUAs in charge of fully recovering the cost of operation and maintenance (O&M) at all canal levels to make them completely financially self-sufficient. The WUA pays the CNA a negotiated percentage of the revenue from collected fees for O&M of the dams, head works and the main canal system; the rest of the income can be used by the WUA, making them financially autonomous. This system helps increase user participation and buy-in and creates an overall stronger footing for the WUAs. O&M costs and levels of fee settings will differ from region to region and may even vary between individual WUAs within the same district that contain multiple watersheds.

With reference to the first hypotheses, measuring the performance of Mexico's institutional reforms is different than that of China and Turkey. Because CNA's primary focus was to implement a quick irrigation management transfer and force management ownership over to farmers, the salient performance indicator to determine its success is typically institutional financial sustainability. Although focusing on this "basket" does not guarantee successful reforms in other countries in the future, the Mexican government was in a financial crisis in the late 1980s and did not have many alternatives to creating a framework for irrigation transfer and institutional capacity.

Turkey

The General Directorate of State Hydraulic Works (DSI) is the main executive agency of the Government of Turkey for the country's overall water resources planning, including design and construction as well as operation and maintenance. In Turkey, more than 80 per cent of large-scale irrigation systems are managed by locally controlled districts (ownership of the infrastructure and water stays with the State). But much of the ownership of water management was turned over to WUAs and farmers because state-owned enterprises had large budget deficits.

Turkish *Irrigation Districts* represent a variation on the standard model in that they are associations of local governments rather than unions of farmers. Voters elect local leaders (many of whom are farmers) and effectivley create accountability links between irrigation district governance and the farmer "clients" of the irrigation systems. A five-member executive committee elected by a general assembly of fifty people, comprising local government officials and farmer representatives, governs systems. Day to day management is in the hands of a hired general secretary and staff member. For the first two years after transfer to villages, the government provided indirect subsidies for system maintenance and then phased out in the third year. Sources of revenue for *Irrigation Districts* are from irrigation fees, membership dues, revenues from goods and services (renting out machinery and equipment), and fines and interest income from the late payments (Cakmak et al., 2005).

In many studies on Turkish reforms, indicators to determine success of the PIM programme focus on fee collection, water use (irrigation intensity), and stakeholder capacity. In one specific case in the Gediz River Basin in western Turkey (Yercan et al., 2009), these indicators validated the importance of successful operation of secondary and tertiary canals and maximising WUE to farmers growing a variety of crops such as cotton, cereals, toboacco, and olives – many of which are relevant crops for parts of India. As is the case in India, farmers typically obtain irrigation water supplied by WUAs or groundwater from wells. Although the average irrigation areas in Turkey are higher than in India, decentralised reform helped to increase yearly irrigation services supplied by WUAs in the Gediz Basin due to a higher fee collection rates. This indicates the effectiveness of the collection programme and the degree to which the users felt the system was worth supporting. The total fee is related to the total irrigated land belonging to the farmer, calculated on the basis of each hectare of irrigated land. Small-or-large-scale farmers pay proportional fees, a system that would greatly benefit the Indian case, since farmers would be more likely to use their water efficiently and minimise wastage.

Furthermore, measuring the fee collection rate is a part of financial self-sufficiency for WUAs. This indicator is particularly important for gauging irrigation management transfer, where the primary goals are to transfer financial responsibility for the system from the government to the users. In the Gediz Basin it is shown that WUAs have made profits (fee collection incomes are higher than expenditures) in recent years indicating that successful PIM reform led to WUE.

There are some inefficiency flaws, however, in the current *Irrigation District* framework within Turkey's water management model. According to Unver and Gupta (2006), the membership of the *Irrigation Districts* is composed of local government administrative units and not water users. The heads of these administrative units (mayors) are elected by an electorate to conduct general administrative duties rather than managing an irrigation system. Consequently, the *Irrigation District* is not directly accountable to water users. The functional linkage between the consumer of irrigation services (farmer) and management of those services is lacking. The result is inefficient management with more administrative duties and farmers unable to exercise direct control over elected management. This results in a lack of farmer participation in many cases in central Turkey where there is limited availability of water.

Inefficient management not only results in a lack of cohesion among farmers in WUAs but also results in financial unsustainability, inefficient water use, and portions of irrigable land being wasted. In this case the benefits of financial sustainablility is strictly awarded to the regional or central administrative management. It remains to be seen if a system such as this could benefit water scarce regions in India where conflicts over water among farmers are commonplace.

PART 4: IMPLICATIONS FOR INDIA AND INSTITUTIONAL DESIGN

Overview of Agricultural Water Resource Development in India

In India, agriculture is of fundamental importance to the national, state and rural economies, contributing 14.6 percent of GDP and over 55 percent of employment (2009-2010). Agriculture provides livelihood for the majority of the population and food security for the country as a whole. About 102 million hectares or almost one-third of the total cultivated area is irrigated. In many regions due to reduced rainfall, irrigation has played a major role in the drive to enabling and enhancing food production. Irrigation gives farmers the security of water supply and enables them to invest in higher yielding crop varieties and increased inputs leading to greater levels of agricultural production than would have been possible under rainfed agriculture.

However, projections of water supply and population growth rates in India are predicting a dark scenario for the future: while the average per capita supply of water will decrease by one-third by 2025, water use will increase by about 50 percent during the same period (2030 Water Resources Group, 2009). Low agricultural water productivity and efficiency, combined with aging supply infrastructure, make severe supply-demand gaps likely in many basins with currently planned crop choices.

Until the early 1970s, most policy interventions in India focused on supply solutions for dealing with increased water demand. These included the construction of large dams, inter-basin transfer of water and small-scale solutions such as rainwater harvesting and other rural development policies. In Gujarat, for example, watershed development programmes have been implemented to alleviate poverty and respond to increased water demand in arid and semi-arid regions of the state. Watershed development programmes were enacted in hopes that agricultural development in both rainfed and semi-arid regions of India would improve by capturing scarce water resources and managing the soil and vegetation. Although successful in many semi-arid parts of Gujarat and western Madhya Pradesh, the programme has not been as successful in other areas thanks to a lack of understanding of hydrologic conditions and poor infrastructure management; thus, they have not alleviated the problems of rural irrigation development and WUE. In some cases, these policies have exacerbated water scarcity, forcing a shift from supply-side to demand side management to address water availability and water use.

Water Availability

India receives an average of 4,000 billion cubic meters of rainfall every year. Unfortunately, only 48% of rainfall ends up in India's rivers and aquifers. A lack of storage procedures, aging infrastructure, and training for water resources officials, only 18 percent of the water can be utilised (UNICEF, 2002). The availability and demand for water resources in India show substantial variations from region to region. Analysis of current water supply and demand in aquifers and river basins show that water scarcity is due to two major reasons:

- Inefficient and inequitable use of and distribution of water; and
- Excessive irrigation development.

Eighty-eight percent of the Indian population lives in areas with some form of water stress or food production deficit. There is a high dependency on some aquifers for production of grain to match shortfalls in river basins that are typically used for surface water irrigation. In Gujarat's semi-arid northern region, one of the most intensively irrigated regions in India, water availability is a concern because groundwater irrigation contributes more than 90 percent of the overall livelihoods of the farmers (Kumar, 2002).

Water Use

Increasing demand from the growing urban and industrial sectors, and concerns for the environment will reduce the share of water withdrawn for irrigation causing a reduction in food production for the growing population. Groundwater used for irrigation has increased from about 40 percent of the net irrigated area in the 1960s to about 57 percent in the late 1990s. Much of this expansion has occurred in water-scarce river basins resulting in increasing the groundwater overdraft in many aquifers. As a result, the expansion of groundwater irrigation, and its sustainable management, are critical issues for future water management. Groundwater uses about 44 percent of the total volume of water used for irrigation but contributes 57 percent of India's irrigated area. For example, in northern Gujarat, excessive withdrawal of groundwater for irrigation is causing massive declines in water levels throughout the region and depleting aquifers faster than they can recharge. According to the Central Ground Water Board, the rate of decline in water levels ranged from 0.91 metres below land surface to 6 metres below land surface during a twenty-year period from1980 to 2000. Although, groundwater wells are easily accessible for farmers to use for crop productivity, groundwater use is unregulated and therefore used without maximising WUE for distribution and long-term crop production.

Water Institutions

In India, designing appropriate institutional mechansisms to allocate scarce water and river flows has been an enormous challenge due to the complex legal, consitutional, and social issues involved. The water sector has been grappling with poor performance and deterioration of infrastructure for irrigation with much of the culpability falling on the current institutions in place. There is little agreement about appropriate institutional arrangements and criteria for successful institutional design.

A wide range of institutional responses has evolved over the last few decades to use and manage the increasing demand for irrigation in India. For example, in India most state governments practise a PIM approach defined by a system of participation of the farmers as beneficiaries with a loose joint role in management of the irrigation system. But there is wide variation in the number of WUAs set up in different states (ranging from more than 10,000 in Andhra Pradesh to less than 100 in Bihar). With the PIM initiatives in place, in some cases partial autonomy was given to WUAs to jointly manage either primary or secondary canals of the irrigation systems with the irrigation agency. In some cases, a chosen group of farmers or a committee collaborates with the irrigation department. In other cases, full autonomy is given to farmers to manage the irrigation management system.

The success of institutional designs such as PIM are contingent upon collaboration of institutions on different levels such as the central or regional, distributary, and farmer institutions to operate and maintain an efficient irrigation system. In India, however, infrastructure in many rural farming areas has remained largely unmaintained and data show that there is an emerging gap between the irrigation potential created and the potential utilised – a prime culprit being the inefficient use of water for agriculture (Gandhi and Namboodiri, 2009). Specifically, WUAs were formed without adequate institutional support and training services for farmers (and therefore have low standards of operation and maintenance) and many WUAs do not employ staff to carry out the basic functions of water management, maintenance and record keeping resulting in poor service delivery. This inefficiency in water use and lack of performance in irrigation are signals to reform the institutional mechanisms currently in place.

Alternative Water Management Institutional Models

Irrigation water management comprise different actors who are required to interact and cooperate for a system to work effectively on a variety of scales: river basin, watershed, hydrologic unit, and at the farm-level. Therefore the structuring of a water management sector should not only be a set of effective 0rganisations but also possess adequate governance mechanisms for better operational capacity among them.

The reform options below for structuring an irrigation management institution are framed in terms of the actors involved, the framework of each individual 0rganisation and its various functions. We demonstrate three alternative water management institutional models and their specific roles and responsibilities as applicable in the India context that incorporate efficient management and administrative solutions. Many of the countries we have presented in this report serve as examples for portions of these management schemes where they demonstrated positive results from their respective institutional changes.

For each model, irrigation service provision involves various stakeholders such as state agencies, quasi-state, farmer 0rganisations, and individual farmers for services to function efficiently. The stakeholders are categorised into three groups: service provider, intermediaries and water users. The service providers supply water to intermediaries, who in turn provide irrigation water to individual farmers or an association of farmers. The intermediaries collect irrigation fees from individual farmers and pay back the providers.

In these three models, the Irrigation Management Board (IMB) is the service provider and provides bulk water to Distributary Stations (the intermediaries). The service contracts between service providers, intermediaries and water users are made for each cropping season that defines the service area for water delivery and irrigation payment. It is assumed that the entity that undertakes operations also maintains the irrigation system, thus making managers accountable.

Furthermore after carefully considering performance indicators from case studies involving successful institutional reforms after PIM was implemented, we determined salient characteristics necessary for irrigation management transfer models to be successful:

1. WUAs need to be financially self-sufficient from the outset. WUAs should be able to collect service fees sufficient to cover operation and maintenance costs so they can be financially self-sufficient.
2. WUAs need to be formed on hydrological units (minors, distributaries, and branch canals and entire canal systems) and should not coincide with administrative boundaries.
3. WUA support groups are required for information sharing and training WUAs over a minimum time frame. Communication between institutional levels reduces information asymmetries and differences of interpretation.

4. A conflict resolution mechanism is necessary to improve equity in water distribution.

To be sure, these models and accompanying characteristics are simplifications of institutions adopted by countries for water management. But they do signal the need to pay attention to the different functions that any water management institution would need to perform to enhance equitable distribution and water use efficiency. All associated 0rganisational charts for each model are in Appendix 1.

Joint Management: State Agency–Farmer 0rganisation

The joint management model emulates portions of the models created under the irrigation management transfer program in Mexico and Turkey and certain water management institutions in China and Vietnam that are typically applied to medium or large-scale irrigation needs (over 150 hectares). There are three institutional levels: (1) Irrigation Management Boards (IMB) at the headwork and main canal level; (2) Irrigation Distributary Stations (DS) at the secondary canal level; and (3) WUAs at the tertiary and farm canal level. Distributary Stations comprise administrators who are intermediaries that serve as arbitrators for conflict resolution and hire contractors on behalf of the IMB. The IMB is established in each regional management area to operate and maintain the main facilities of the irrigation systems such as diversion structures and the main canal. Since this model is suited for large irrigation schemes, the IMB is at the primary hydrologic unit level and the Distributary Stations are at the district level.

Under the joint management model, farmers benefit from hired contractor irrigation services on a two-year term limit and pay irrigation fees for the land irrigated through the WUA. The contractor model, designed from the successful institutional arrangement in China, serves as a way of managing irrigation systems and provides much-needed training to farmers for operation and maintenance and efficient water distribution. Contractors help improve overall performance and productivity by focusing on the relative water availability, crop type suitable for the water available, water delivery performance, and consistent fee collection from farmers. Once the term limit of the contractor is completed, joint-management training (such as those conducted in Mexico during the implementation of their IMT programme) commences for a short period before the management of tertiary canals is delegated to the WUA.

In areas such as Guangdon Province in eastern China, where tertiary canals are well maintained and lined, the Water Supply Company (IMB) uses an innovative approach where flow metres are distributed to WUAs that collect water charges. Contractors use these to verify complaints by farmers that they did not receive the water they were billed. In Guangdong Province these reforms have increased the irrigation areas served by 10 percent and points to the effectiveness of introducing private sector incentives in water management (Johnson et al., 2004).

Functionally similar to the Regional Directorate Offices under the General Directorate of State Hydraulic Works in Turkey, the IMB is divided into departments of which O&M is the strongest. As is the case in Vietnam, in order to sustain operations for water management the IMB derives additional revenue by participating in design and construction of new primary canals and/or providing oversight for the restructuring of old canal systems. With the involvement of farmers, the IMB and WUAs provide a good framework for improved O&M of the irrigation system (Stacey, 1999). The salient characteristic of joint management is the movement towards procedures for providing irrigation services within hydrologic boundaries of a watershed and not solely based on administrative boundaries.

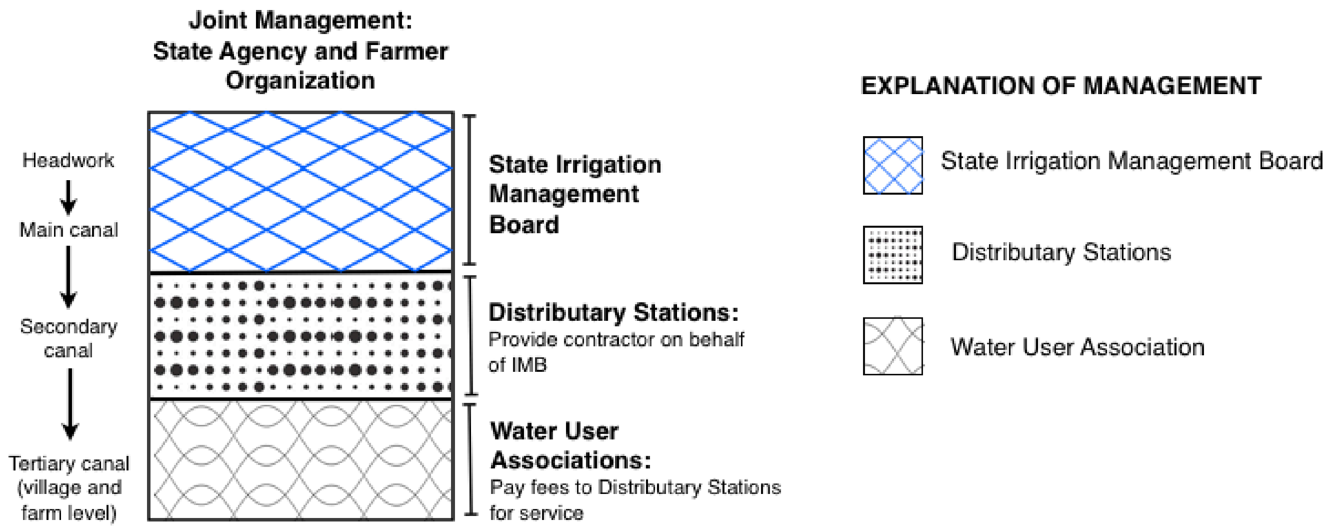


Figure 2. Joint water management model: State agency and farmer 0rganisations.

Table 5. Advantages and disadvantages for each actor under joint water management schemes.

	Irrigation Management Board	Distributary Station	Water User Associations	Farmers
Advantages	Can derive additional revenue from other services such as design and construction services.	Resolve disputes more efficiently than IMB because DS is responsible for contractor.	Entitled to the provision of agricultural inputs such as fertilizers, seeds, etc.	Provided with a contractor on behalf of IMB to increase WUE and benefit from irrigation service.
Disadvantages	Cannot provide recommendations or impose penalties to ensure proper distribution and sharing of water.	Liable for any malfeasance on the part of the contractor.	Potential for conflict with contractors in terms of price setting, water use limitations, and lack of understanding of training.	Must pay irrigation fees for the irrigated land through the WUA. Not involved in decision-making about management activities such as water distribution and conflict resolution.
Example	Mexico, Turkey, Chile	China, Vietnam	China, Laos, Vietnam	China

Shared Management: Quasi-state–Farmer 0rganisation

The shared-management model is partially framed after the PIM program in Turkey which operates within district-level irrigation systems. The Turkish model is based on an association of relevant local government 0rganisations, rather than a complete association of water users. However, with this new shared-management system, the boundaries are based upon hydrologic considerations rather than district administrative boundaries. This system was implemented in Mexico and proved to be a successful for easy and efficient water delivery. At the tertiary and farm canal level, management is still done by the WUA. The IMB comprises both government staff and farmer representatives and manage the main canal. In a shared management system the Distributary Station mainly act as an arbitrating mechanism for conflict resolution once water is divided to tertiary canals but is maintained jointly by Distributary Station staff and representatives from WUAs. Staff at the Distributary Stations work concurrently with WUAs to operate and maintain both the secondary and tertiary canal system. In Chile, a similar reform was undertaken at the secondary canal level, where water communities served as intermediaries and advisers to both the primary (IMB) and tertiary canal members (WUAs).

The operation and maintenance component is based on the Vietnamese model where the IMB signs a water delivery contract to the WUA (headed by a board) to deliver water for agricultural production to farmers. Farmers will then pay for the water service directly to the WUA-established management board that will in turn be used for coordinated operation and maintenance with the State.

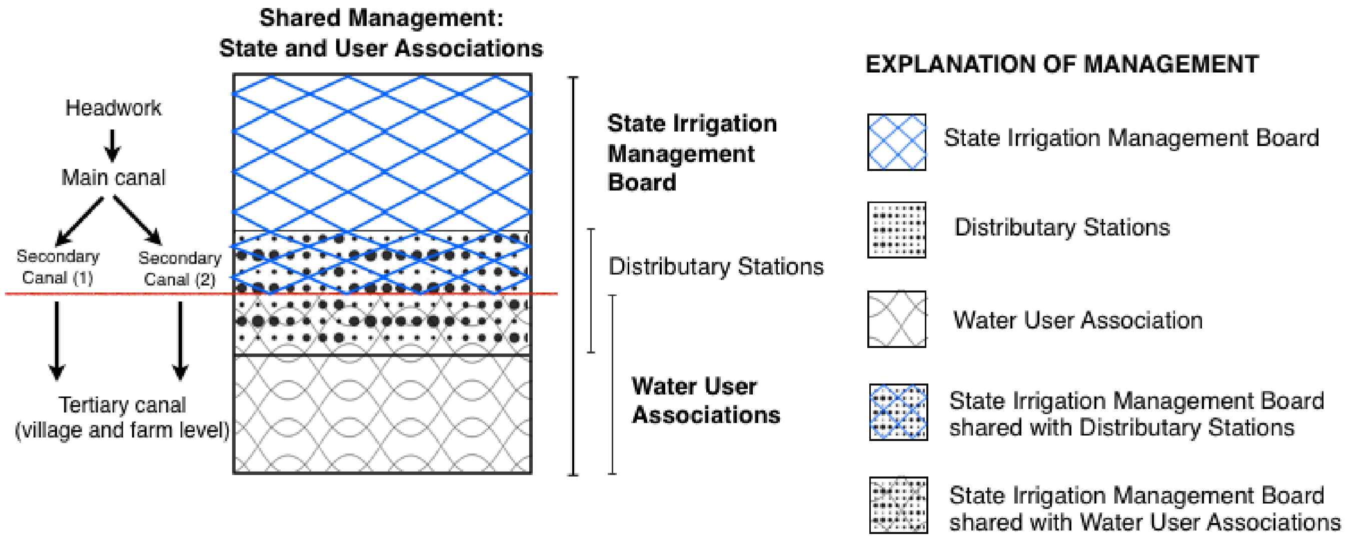


Figure 3. Shared water management model: state and water user associations.

Table 6. Advantages and disadvantages for each actor under shared water management.

	Irrigation Management Board	Distributary Station	Water User Associations	Farmers
Advantages	Representation from both state agency staff and farmers.	Better understanding of the long-term needs of farmers. As a result resolve disputes more efficiently.	Better representation within the IMB.	Gain access to information about change in policies.
Disadvantages	Maintain secondary canal using more financial resources	Must help resolve conflict of interests between the IMB and WUAs thereby increasing the level of responsibility and using more financial resources.		Farmers have partial decision making about management activities such as water distribution. Heavier penalties against noncompliance of rules set by WUA.
Example	Mexico, Turkey	Turkey, Vietnam	Turkey	Laos, Philippines, Vietnam

Village-level Management by Farmer Water User Associations

The village-level management model is applied in small-scale irrigation schemes (less than 50 hectares) such as those in Vietnam, Philippines, Laos, and Sri Lanka. In this model farmers organise and manage irrigation systems by setting up WUAs based on hydrologic boundaries. Farmers actively participate in determining the service supply, fee rates, and fee collection mechanism for their agricultural production. Under this model of management, the IMB takes the place of Distributary Stations at the secondary canal and train farmers for operation and maintenance, fee collection and various other duties. Under village-level management, the secondary canal is operated by WUAs but maintained collaboratively by both the IMB and WUA. Within this structure, the IMB is responsible for repairs on the main canal while WUAs are in charge of canal repairs and cleaning on the secondary and tertiary canals. In Laos and portions of Cambodia, irrigation responsibilities are rotated for tertiary canals among farming heads elected by the WUA. For village-level management models in the Philippines, WUAs are fundamentally implementing the agenda of both the irrigation agency and conflict arbitrators. Their main functions are to maintain the secondary canal, distribute water to the tertiary channels, and then to collect the water fees from water users on behalf of the IMB. Appendix 2 shows the primary service provisions from WUAs to water users.

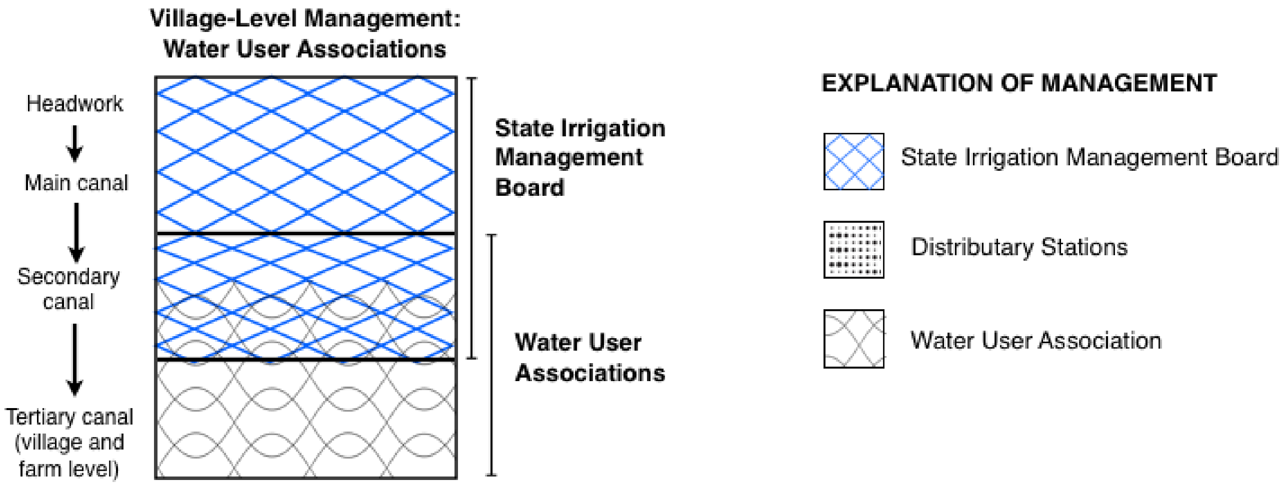


Figure 4. Village-level water management model: water user associations model.

Table 7. Advantages and disadvantages for each actor under village-level management.

	Irrigation Management Board	Distributary Station	Water User Associations	Farmer
Advantages	Have the mandate to resolve water disputes.	--	Management board and irrigators are elected.	Farmers have partial decision making powers about management activities such as water distribution.
Disadvantages	During times of extreme water disputes, IMB must elevate cases to federal or regional water institutions. IMB must spend more resources to train farmers how to operate and maintain the canals and do not have Distributary Stations to rely on training and advisory programs.	--	Must be trained in conflict resolution and other responsibilities by the IMB.	Participation from farmers is voluntary disrupting the collective action necessary for efficient and equitable water distribution.
Example	Australia, Turkey	--	Sri Lanka, Turkey, Philippines, Vietnam	Laos, Philippines, Sri Lanka

Table 8. Summary of the key actors and essential management functions for the three alternative water management models.

	Joint Management (State-Farmers)			Shared Management (Quasi-State)			Village-Level Management		
Responsibilty	Irrigation Management Board	Contractor and Distributary Station	WUA	Irrigation Management Board	Irrigation Management Board and WUA	WUA	Irrigation Management Board	Irrigation Management Board and WUA	WUA
Planning	X	X		X	X	X	X		X
Operation	X	X	X	X	X	X	X		X
Water distribution	X	X	X	X	X	X	X		
Infrastructure Construction		X	X		X		X		X
Infrastructure Maintenance	X	X	X	X	X	X	X		X
Conflict Resolution		X			X			X	

Table 8 summarises the roles that key actors are expected to play for different management functions in the alternative institutional models described above. Financing is an important dimension defining the nature of these models. All of the management models have similar financial arrangements (Table 9). The management entities obtain revenues from collecting irrigation fees and additional amounts paid by farmers depending on the system for O&M and construction of tertiary canals, and governments finance the capital investments for main infrastructure (Trung et al, 2005). Following general guidelines issued by the federal and state water resources departments, lower and upper limits for an irrigation fee are established as well as a revenue-sharing mechanism for the involved entities.

Table 9. Financial arrangements in the alternative management frameworks.

Item	Entity Responsibility
Capital financing	-
Main facilities	Federal or State government
Tertiary canals	WUA
Operation and maintenance financing	WUA
Fixing irrigation fee	Irrigation management board
Setting revenue sharing mechanism	Federal or State government

PART 5: CONCLUSIONS AND RECOMMENDATIONS

This report has endeavoured to summarise some of the key indicators to determine successful institutional reforms in various countries that have relevance to the India context. We sought to provide some suggestions for approaches to improve future analysis. The following is a general summary and presentation of conclusions that could help complement existing research.

- With reference to the first two hypotheses of this report, it can generally be concluded that application of hydrologic indicators across regions provides beneficial information on the differences in rainfall variability and relative water availability.

- An important parameter to determine irrigation management calculations such as equity in water distribution is effective rainfall. Irrigation in the winter season, with very little rainfall changes differs from high water demand seasons such as the summer. Therefore, the method used to calculate effective rainfall becomes very important and must be standardised across systems.

- The absence of scientific data greatly compromises efforts to compare across countries with regions in India because of its variable geographic and agro-climatic zones. These data gaps should be addressed and resolved for comparison purposes and to identify the implications for irrigation management policy options (such as the way long-term planning for irrigation distribution is calculated).

- Scientific and social indicators are complementary. Application of both types of indicators proved to be useful to gain better understanding of the dynamics of institutional reform and irrigation management by regional managers and farm-level water users.

- To maximise WUE and minimise conflict among water users, water resource management must be conducted along hydrologic boundaries. Matching the administrative (political) boundaries and natural (hydrologic) boundaries is one of the most challenging issues in water resource management. Nevertheless, this system is necessary not only for management purposes but for consistent scientific data collection over time to inform decision-making.

Synthesis of Best Practices for India

The following best practices provide valuable lessons for how to achieve WUE with different institutional models. The best practices included in this report are of two types: those to be emulated within the country of occurrence and those that can be emulated in India. We presented a variety of institutional models with different operational effectiveness that can be extrapolated to new or existing institutional frameworks.

Mexico

Mexico offers two primary best practices: (1) ensuring the farming community is educated and is able to understand and take advantage of the opportunities offered by irrigation management transfer and (2) increased transparency and accountability to all stakeholders on water resources availability, allocation and use through river basin councils. Additionally, as part of the transfer program, the CNA transferred the majority of the maintenance equipment to farmers so that they would have the equipment required to maintain their respective ditches and drains. Access to maintenance equipment was a strong incentive for farmers to accept the transfer programme. The most noteworthy feature of the Mexican irrigation management transfer program is the supportive legal and administrative changes offered to farmers before, during, and after the irrigation management turnover process.

China

Among the best practices that China offers is that canal O&M, water distribution, and water fee collection in large irrigation systems are increasingly being taken away from village committees controlling tertiary irrigation management. This role is increasingly contracted out by village leadership to private individuals with strong financial incentives to save water and promote WUE. Also, many of these contractors have an obligation to invest in rehabilitation and construction of canals to reduce the annual volume of water purchased from the irrigation district.

Another best practice in China is the shift from irrigated rice to rainfed corn in some central provinces, which reduces pressure on groundwater resources. This validates the importance of "crop type" as an important performance indicator for determining successful institutional reform. According to Liaoning water officials, shifting to a different a crop helped raise the average depth to the water table from 34 metres below land surface to 18 metres below land surface (Shah et al, 2004). Furthermore, the China Ministry of Water Resources promoted the approach of WUA as good practice through rigorous training programmes (Wu and Mckay, 2005). These have included numerous field visits and dialogue between government officials, contractors, and WUAs.

Turkey

Turkey offers many practices that made for a more efficient method for implementing IMT helped existing employees of DSI, and transferred the benefits of that assistance to WUAs. In the early stages of the irrigation transfer programme the government provided subsidies to support a new water user 0rganisation primarily for system maintenance. Once a WUA is established (generally after 2 to3 years) the WUA is responsible for its own operation and maintenance costs. Training and support was also provided by the centre (DSI) with a clear mandate from senior management that local DSI staff were to support this initiative. This active support and guidance from staff provided a good framework for training and supporting WUAs. A supporting factor in the programme was that DSI O&M staff on the transferred systems were not made redundant but rather transferred to other duties or employed by a new irrigation 0rganisation. Furthermore, staff are well paid (and therefore less corruption between staff and water users) and thus transfer of O&M functions to water users did not result in loss of income.

Recommendations for Institutional Reform

Even though the present evaluation of water institutional reform and WUE in agriculture is based on a small sample of cases, it does have many implications for institutional change in India. Based on the information gathered and analysed, institutional changes are not uniform across the globe and require many aspects to garner success. A multidisciplinary effort is necessary to enhance the efficiency of institutional reform and therefore help the agricultural sector maximise efficient water use and distribution. Detailed policy recommendations are listed below.

1. The importance of the knowledge of the hydrological cycle is fundamental to solving a variety of water management problems. For long-term institutional change, a basin or watershed perspective needs to be maintained. A key feature of decentralisation should be an increasing importance attached to river basin or watershed irrigation management. Basin WUAs can be designed and formulated on hydrologic rather than on administrative boundaries. Understanding and interpreting the hydrology is important for water management institutions and/or subsequent reform because it allows for an integrated approach to management as well as for resolving regional water allocation conflict.

   One hydrological issue that is little understood by policymakers is its spatial variability. One of the current paradigms, supported by reason as well as practice, is that good water resources management should be structured according to the geography of the natural basins with the space partitioned by delineated watersheds. This facilitates a fairly general view of the problems associated with water management and better decision-making.

   These concepts are needed as part of the push to incorporate more scientific data measurements, data management, and dissemination to improve long-term WUE beyond basic administrative institutional reform. Scientific data collection and monitoring (including field reconnaissance) should be undertaken before reform is considered both during management implementation and within consistent intervals post-reform. Some of these data collection efforts should include:

   a. **Groundwater-level measurements and monitoring** in existing wells to determine water-level fluctuations in shallow aquifers
   b. **Canal flow measurements** by obtaining periodic measurements of discharge (the quantity of water passing a location along a canal)
   c. Periodic measurements of precipitation (could be monthly, quarterly, annually)

2. Another point that is little understood is the time-scale variability on which various natural (hydrologic) processes take place. This may lead to mismanagement, especially over long time periods. For example, in the case of rainfall, effects such as water-level increases in rivers at various intervals can be observed, since in large basins, change can be days, weeks or months. Individual cases for WUE distinctly vary. In some cases, hydrologic changes occur very quickly such as during flash floods or short period rainfalls when the effects appear immediately and water levels in aquifers and rivers have dramatic changes. In these situations, measurement training to effectively help deal with irrigation management, particularly distribution, will be necessary. As a result, corrective measures and adaptation for immediate versus long-term data collection must be put into place and taught to technical staff at secondary and tertiary canal systems.

3. For small-scale irrigation users, a contractor from outside the village should be used for repairs and other maintenance issues. This will create a sense of ownership and belonging among the users, improve maintenance of the infrastructure, bring financial discipline, cost recovery, better regulation and overall sustainability. This also alleviates the financial burden of the government

in terms of subsidies and manpower reduction. The most efficient method of accomplishing the contracting method is to give incentives leading to water use improvements in the first year as this management policy requires minimal technological investment (depending on fee payment structure) for reducing overall water use. The contractor would then incorporate WUAs into the management of the irrigation operation. This is a cost effective way to maintain efficient functioning of irrigation systems and performance without additional investment.

4. In order to implement PIM by reforming existing institutions in India, governments must understand that the primary goal is to increase water use efficiency and how to measure its success. Therefore, to assess the transfer of irrigation management to WUAs the performance of the irrigation system must be measured, describing the financial and physical sustainability of each type of irrigation system. In order of importance, the three indicators include:

    a. The **total maintenance expenditure per metre** of the canal measures the quality of maintenance. Cleaning canals by removing weeds and silt is the major maintenance activity undertaken by most villages to keep their irrigation systems functioning.
    b. The **quality of water delivery service**.
    c. Measuring the effectiveness of **water fee collection**. The effectiveness of water fee collection is crucial to the financial sustainability of transferred irrigation schemes. In some cases O&M costs are derived fully from water fees collected. The proportion of water fees collected directly affects the quality of maintenance and water delivery services.

5. Central governments or irrigation departments should promote training for WUAs, assign the roles and responsibilities of different actors, and extend technical support towards management of the irrigation system. Although this initially involves transaction costs, in the long run this would improve the efficiency and sustainability of the irrigation system. If farmers were convinced that the associated benefits of their participation exceed the costs, water users would extend their active cooperation. Farmers are willing to pay the irrigation charges provided they are assured of dependable supply. A sample listing of training courses for WUA leaders and staff can be found in Appendix 3.

6. If institutional reform measures are undertaken in areas where a current management system does not exist then two additional performance indicators should be taken into consideration:

    a. **Dependability of irrigation interval** determines whether the interval between irrigations is either planned (such as in a planned irrigation rotation regime) or dictated by the crop's soil moisture status. This indicator allows irrigation planners during reform projects to determine whether a crop is contributing to inefficient use of water based on the environmental conditions of the region.
    b. **Main system water delivery efficiency** measures water discharge at main canal intakes and offtakes to the tertiary unit. This value changes based on the season (monsoon or drought) in which it is measured.

The complexity of the problems dealing with agricultural WUE and institutional reform requires technical expertise at various levels of management. This implies not only individual capacities but also institutions with sufficient strength and independence to guarantee rigorous work. Some characteristics to take into account when deciding upon reform possibilites in India include the construction cost of a water distribution system with the same characteristics of those in other countries. Much of the material used in other countries are mined or manufactured domestically, so material costs may be cheaper.

For long-term considerations after institutional reforms have been implemented, environmental impacts will soon have to be addressed. To alleviate the burden of a brand new monitoring protocol to be put into place, our third hypothesis becomes increasingly important. Not only will scientific data measurements be able to discern whether a particular reform measure is operating efficiently and increasing WUE, but can also serve a secondary purpose of measuring groundwater fluctuations and overexploitation of nearby aquifers.

Achieving these changes involves better collaboration between the technical environmental community as well as better participation from farmers. This allows for a more unbiased evaluation of the needs of the IMB, Distributary Stations, and WUAs, and calls for a formal advisory group that includes all parties – particularly farmers so that their rights to political action are not compromised in making decisions regarding water distribution, fee collection, water use, and other efficiency targets. Such collaboration cannot be imposed from above, but will have to be designed based on particular local characteristics. This report has offered alternative institutional design options; adopting and executing them will depend on recognition that WUE is no longer an option but an imperative for India.

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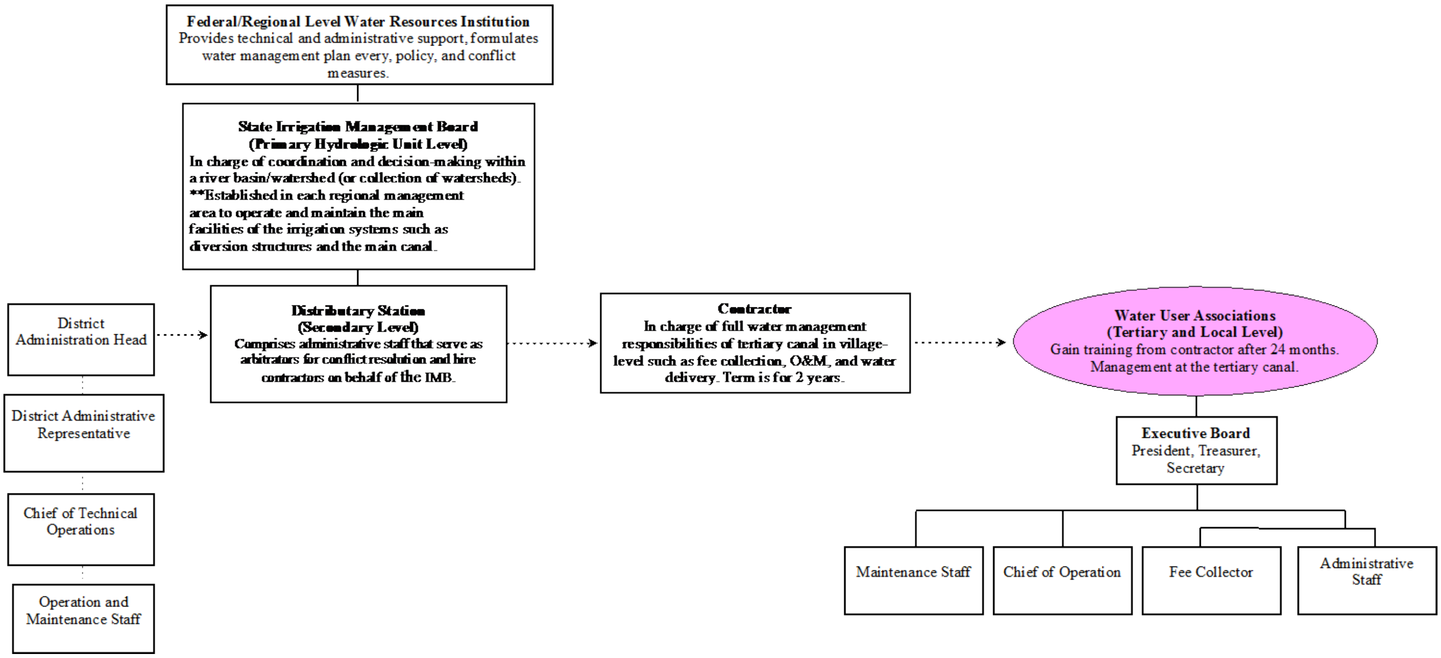
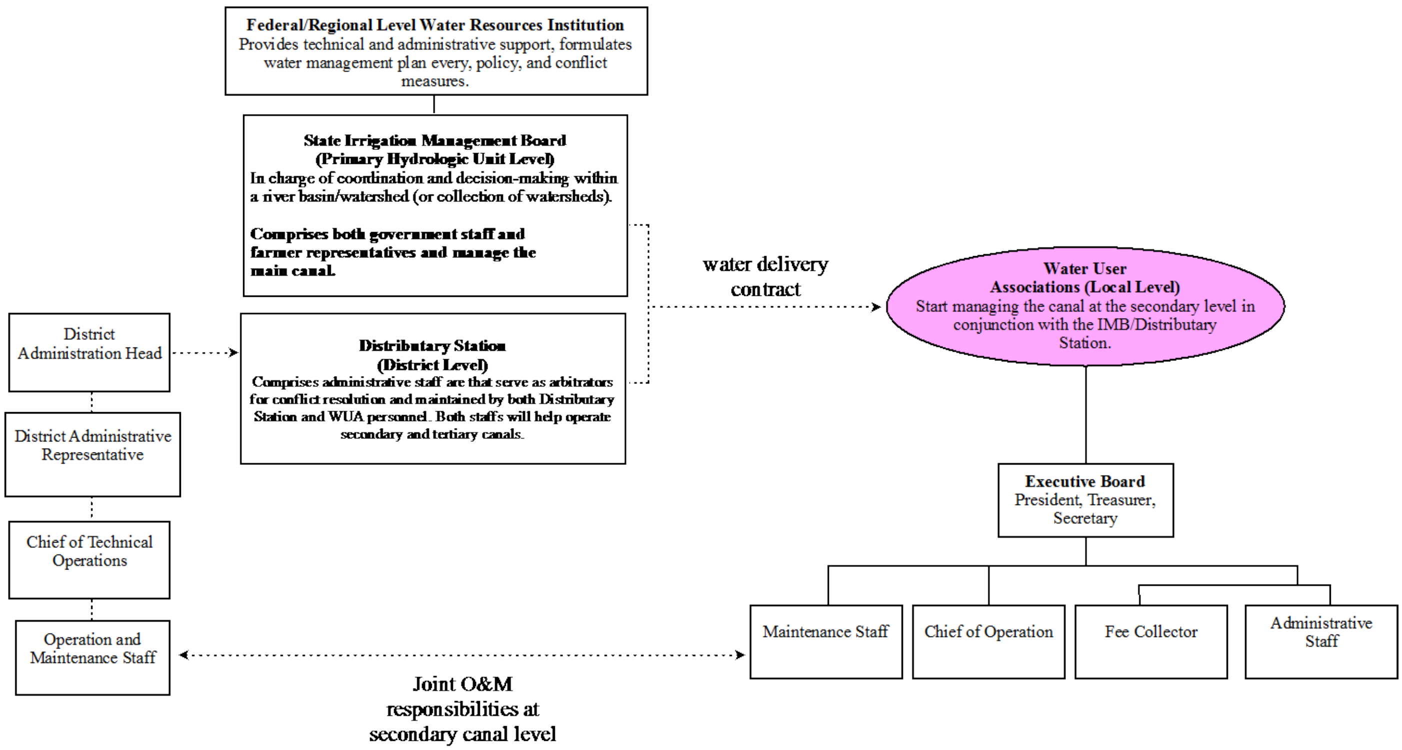
Appendix 1: Water Management Institutional Reform Organisation Charts

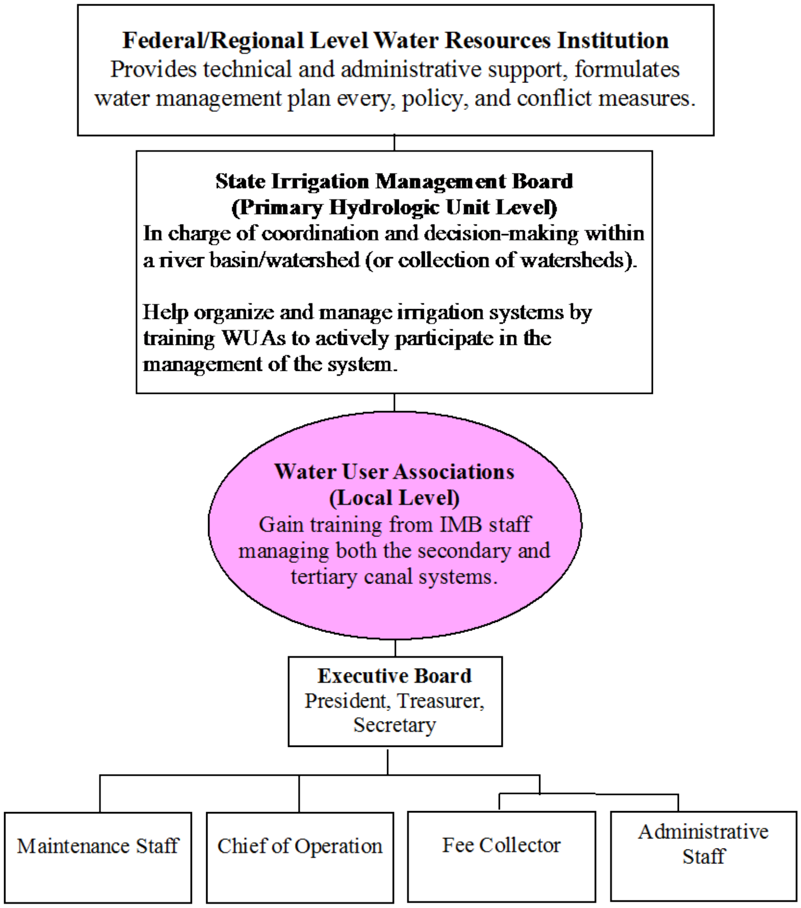
Joint Management: State Agency-Farmer Organisation



Shared Management: Quasi State-Farmer 0rganisation



Village-Level Management: Farmer Water User Associations



Appendix 2: Operation and Maintenance Service Responsibilities from WUAs to Water Users

Type of Service	Description
System operation	Preparation of seasonal irrigation schedule Delivery of irrigation at the right place and time Monitoring of operations Technical advice on to use water more efficiently
System maintenance	Preparation of seasonal maintenance plan Cleaning of canals and drains Maintenance and repair of structures
System improvements	Minor system improvements Provide information on esternally funded system improvement programs
Administration	Preparation and presentation of O&M budgets Setting and negotiating fee levels Administration of fee collection Inform users about fee levels

Appendix 3: Training Courses for WUA Managers and Technical Staff

Transfer Timeframe	Training course
Pre-transfer	What is irrigation management transfer?
Pre-transfer	Promoting and initiating irrigation management transfer of irrigation districts
Pre-and-during transfer	Management course for leaders of WUAs
Pre-and-during transfer	Professional course on operation of secondary canal systems
Pre-and-during transfer	Design of irrigation plans for WUAs
Pre-and-during transfer	Water distribution
During and post-transfer	Technical improvements in canal irrigation
During and post-transfer	Efficient use of water and energy
During and post-transfer	Planning the improvement of production

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