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Restoring Groundwater in Punjab, India's Breadbasket:

Finding Agricultural Solutions for Water Sustainability

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Columbia Water Center's mission is to creatively tackle global water issues through innovations in technology, public policy and private action. Combining the rigor of scientific research with the impact of effective policy, we aim to design reliable, sustainable models of water management and development that can be implemented on local, regional and global levels.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY 1
THE WATER-AGRICULTURE-ENERGY NEXUS 2
EVALUATING WATER-SAVING STRATEGIES 4
DISCUSSION AND NEXT STEPS 4

EXECUTIVE SUMMARY

In the past half century, India has successfully transformed itself from a country of recurring famine to a grain surplus nation, in large measure through the rapid expansion of irrigation—irrigation that has increasingly come from groundwater. However, this success has come at a cost. Today the rapid depletion of groundwater across much of India threatens the success of the Green Revolution, hurts efforts to provide safe drinking water and contributes significantly to the instability of the nation's electrical grid, as well as and to the poor fiscal condition of states that provide subsidized electricity for agricultural pumping. Punjab, the "breadbasket" of India, is at the heart of this crisis.

The early success of the Green Revolution in Punjab prompted the Government of India to target the state as a source of rice and wheat for the national food procurement and distribution system, at a guaranteed price. Subsequently, the state government of Punjab provided electricity for agricultural pumping at a fixed seasonal cost, irrespective of quantity used. These two factors led to the establishment of a rice-wheat annual crop rotation, which consumes much more water than the average annual rainfall and renewable supply in the region, leading to groundwater depletion. In spite of the negative long-term consequences of these policies, policymakers have long considered these incentives to be politically untouchable.

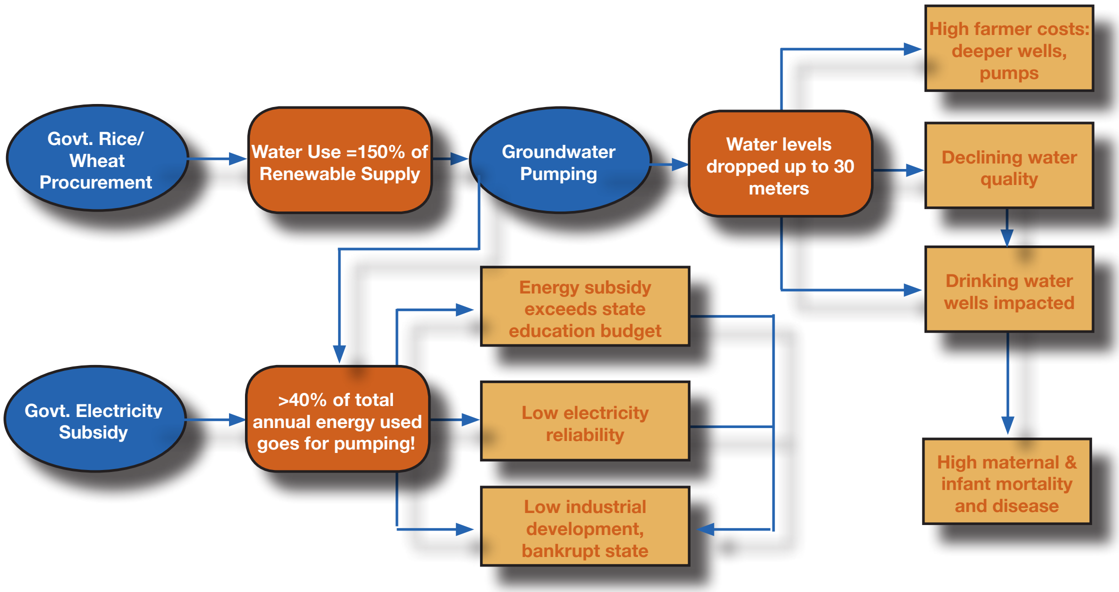
Given the political constraints limiting broad scale policy changes, our research was designed to answer two key questions. First, ***can water use in rice-wheat cropping be reduced, and can the crop systems water use be brought into balance, even if subsidy and procurement policies are not changed***? Second, ***can large-scale contract farming promote crop diversification and introduce crops that are not as water intensive, independent of policy changes?***

The Columbia Water Center (CWC) and the Punjab Agricultural University (PAU) are collaborating on field research in Central Punjab to explore the practical implications of both questions, by working directly with farmers and agrocorporations to develop and test scalable solutions for saving water in agriculture.

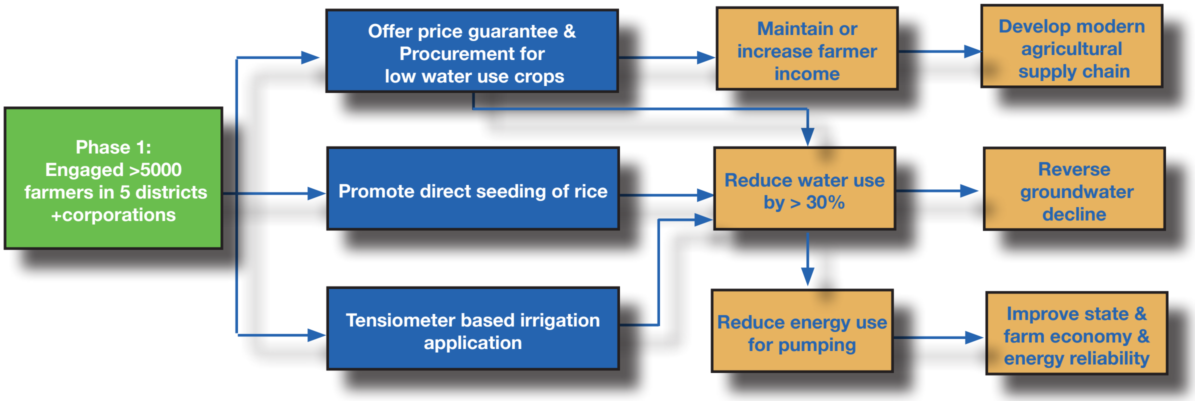
This white paper presents the initial results of an investigation into the ***first question***. In the first phase, the research attempted to identify one or more technologies or practices that are purported to save water in rice cultivation, and were attractive to farmers for adoption through a structured field test. In the second phase, the project team has developed and is pursuing a strategy to rapidly recruit farmers to scale up the application of the ***tensiometer***, the most successful of the approaches tested in the first phase.

The following figure illustrates a conceptual decomposition of the factors contributing to the groundwater depletion in Punjab, and its impacts followed by a sketch of the solution strategy we are exploring. Initial surveys of farmers helped establish that the primary reasons for the high water usage were the guaranteed income provided by the rice-wheat procurement, even though progressive farmers were able to generate much higher income from vegetables, which are subject to significant price

Punjab: India's Green Revolution Success Threatened



Solutions: Pepsico Foundation-Columbia Water Center-Punjab Agricultural University



fluctuation. The surveys also revealed that farmers were concerned with groundwater depletion due to increased well drilling and pump replacement costs associated with the poor energy reliability. There was willingness to pay to get reliable electricity, and to adopt water saving technologies, especially for rice. These observations motivated an exploration of the 3 solutions indicated in the figure. The intention was to identify one that farmers were most likely to adopt and to then seek a scaling up of that strategy.

In 2010, 525 farmers participated in an experiment to test direct seeding of rice and the use of

Potential Impacts from Scale Up of Tensiometer Application

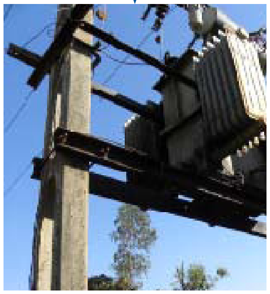
In Phase 1, water saved by the farmer cohort using tensiometers averaged across all farmers was 22%, including non-adopters. A typical savings rate for farmers in districts where a more consistent extension effort was applied was closer to 33%.

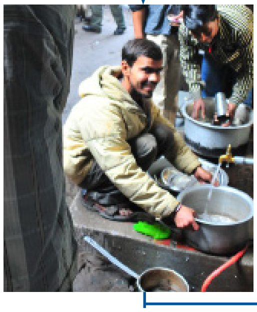
Based on these results, if 66% of Punjab farmers growing rice adopted tensiometers . . .

. . . they would save about 81 million Kwh/year of electricity.

. . . they would save 1.05 million litres of water per hectare per year . . .

That savings could . . .





At 40 liters per capita per day . . .

Save 48,000 tons of carbon . . .

. . .and save 149,736 million Rs ($3 million)

₹

. . .this equals one year's fresh drinking water needs for 97 million people.

tensiometers as mechanisms for water saving in rice. Rice was selected since the average water application is 1.8 m/season, compared to 0.6 to 0.7 m in average annual precipitation in the region! Direct seeding is a method of rice cultivation that avoids transplanting and continuous flooding of the rice field. The tensiometers are soil moisture sensors that are used by the farmer to decide when the moisture levels have dropped enough to warrant irrigation. Each farmer conducted paired experiments, where 1 acre of land was devoted to the test, and the balance planted or irrigated using existing practices. Results for water savings are consequently determined through a comparison of the control plot vs experiment plot for each farmer. A specially modified tensiometer cost Rs 400 (~$8) and one was used per acre. Farmers recorded their frequency and duration of irrigation, and hence total water and pumping energy use and rice yields from each plot.

Both techniques were effective in saving water. On average, the farmers testing tensiometers recorded a modest (1%) but not statistically significant increase in yield, while those testing direct seeding of rice had highly variable results with some recording significant decreases in yield. In follow up surveys, 85% of the farmers testing tensiometers expressed enthusiasm for adopting and popularizing the use of tensiometers. Consequently, in Phase 2, which is currently in progress, we are exploring how the use of tensiometers can be best spread into the agricultural system, with the goal of targeting 5000 farmers for adoption. In Phase 1, the water saved by the farmer cohort, averaged across all farmers (adopters and non-adopters) was 22%. A typical savings rate for farmers in districts where a more consistent extension effort was applied was closer to 33%. If 66% of Punjab farmers growing rice adopt tensiometers, then significant savings in water and energy use could be realized, with significant implications for regional sustainability as illustrated below. We feel that given the very limited amount of training required in the use of the tensiometer as designed for this project, the low cost, and the demonstrable savings, achieving this level of market penetration is eminently feasible.

This project was funded by the ***PepsiCo Foundation*** as part of a multi-country initiative, “Improving Rural Water and Livelihoods Outcomes”, that targets multiple aspects of climate variability and water stress and develops solutions for regional water sustainability and rural livelihood improvements.

UNDERSTANDING THE WATER-AGRICULTURE-ENERGY NEXUS IN PUNJAB

Background and Overview

Throughout history, the strength of the annual monsoon in the Indian sub-continent has significantly affected rural livelihoods. Crop yields depend directly on intra-seasonal rainfall statistics that vary by season and by year. Since the devastating famine of the mid-1960s, agricultural policymakers in India pursued one central objective: securing national food security by augmenting domestic food production. A key strategy by Indian governments was to aggressively implement policies to promote large-scale irrigation for agriculture to reduce vulnerability to the inclement rainfall.

Governments at different levels set up policies to provide farmers with cheap institutional credit and other large subsidies to encourage private investment in irrigation, including tanks, wells, pump-sets and irrigation structures. In addition, energy for irrigation was heavily subsidized, with user fees and tariffs kept far lower than the cost of operation. In the 1990s, as the number of irrigation wells and associated transaction costs grew exponentially, officials replaced metered pricing of electricity with a flat rate system, with fees typically linked to the size of the pump motor.

As a result of these policies almost half of the total agricultural land in India is now irrigated (Siebert et al., 2005). As the population and its food needs have grown, agricultural intensity, i.e., the number of crops produced per year, has also grown, with widespread cropping even in the traditionally dry season. Consequently, today the ability to provide a reliable source of irrigation water is critically important for the success of agriculture.

Policy measures introduced to achieve the dual-objectives of increasing food production and improving food availability included the institution of minimum support prices for producers (implemented through obligatory procurement), using open market operations to maintain inter and intra-year price stability for crops, the creation of buffer stocks and the distribution of foodgrains at controlled prices through the public distribution system (Chand, 2005). Coupled with the introduction of high yielding varieties of wheat and rice, these interventions turned India from a nation plagued by massive shortages into a grain surplus country and allowed it to attain food security (in terms of grain) at a national level. Foodgrain production in the nation has nearly doubled, rising from 120 million tons per year in 1960 to 210 million tons today.

However, a district level analysis of agricultural growth during the 1960s-80s shows that this growth in productivity was not equally distributed (Bhalla and Alagh, 1979). While many irrigated districts in the northwestern regions including Punjab, Haryana and western Uttar Pradesh (U.P.) and in South India recorded a significant increase in the yield and output of wheat after they were introduced to new seed-fertilizer technology, there was no significant production growth in the other eastern, central and southern regions where irrigation was less prevalent and output continued to be determined by the vagaries of the monsoons.

Punjab: The Breadbasket of India

For Indians, the very mention of the word ‘Punjab’ conjures up visions of lush green fields, rich alluvial soils and water aplenty. Three year-round rivers, the Sutlej, Beas and Ravi, flow through the state. In addition south-western Punjab is home to the Ghaggar, which flows mostly during the monsoon season. These rivers hold a water potential of about 1.79 million hectare meters (Tiwana et al., 2007). Punjab also has an extensive network of canals, which have provided a big boost to agricultural growth.

Over the past half century, the Government of India has invested more than Rs. 70 million to promote agriculture in Punjab, Andhra Pradesh, Tamil Nadu, Gujarat and other states. Of these areas the state of Punjab emerged early on as the clear leader (Tiwana et al., 2007), with a fecundity that earned it the title of “Breadbasket of India”.

Comprising a mere 1.57 percent of the India’s total geographical area, today the state of Punjab produces 12 percent of the nation’s 234 million tons of foodgrain, and nearly 40 and 60 percent of the wheat and rice that buffer the nation's central pool for maintaining food stocks and operating public distribution system for the poor (Tiwana et al., 2007) (GoP, 2010).

However, this productivity increase has come with a cost. As the epicenter of the Green Revolution, the state of Punjab today faces significant challenges with respect to water and energy. Since the late 1970s, irrigation has increasingly shifted from surface canal systems to extensive pumping of groundwater, leading to precipitous declines in water levels and a dramatic increase in energy required to grow crops.

Understanding both the magnitude of the decline in the water table and the factors driving it is critical for developing a strategy for solutions. In addition, given the huge amount of water it takes to grow rice, the economic, policy and behavioral structures and attitudes that have supported the rapid spread of this crop merit special attention. Given Punjab's role as a significant contributor to the national grain procurement system, a failure of agriculture in the state due to increasing energy expenses and/or depleting groundwater could have far reaching consequences for India.

The climate of Punjab is typically subtropical with hot summers and cool winters. The average annual rainfall ranges from around 500 mm per year in the south to more than 1000 mm in the north and northeastern sub-mountainous zone (Fig 1a). For both areas, there is a significant inter-annual variation in rainfall across years (Fig 1b). Low annual rainfall coupled with high inter-annual variability is of particular concern in south and south-western regions since the area is semi-arid, the average land holdings are small, and the small and marginal land-holding farmers are generally very poor.

Coupled with the fact that along with much of India, Punjab experiences strong monsoon rainfall during the short span between June and September, it becomes evident that while on average sufficient water may be available, periods of excesses are followed by periods of deficit (Fig 4). Shortages of water inevitably have direct impacts on food production and other productive uses of water.

Evolution of cropping patterns

Foodgrains have long been the predominant crop in India, accounting for two-thirds to three-fourths of gross cropped area since the early 1950s. However, the foodgrain sector itself has seen substantial changes over the same period.

Over the last several decades, the crop selection in the state has shifted from an erstwhile diversified mix of traditional crops such as wheat, maize, pulses and vegetables to predominantly rice-wheat cultivation. While in the past summer crops included both cotton and maize and winter crops included wheat and maize, today the vast majority of farmers cultivate seasonal monocrops, growing only wheat in the winter and rice in the summer. In the period between 1970 and 2005, cropping intensity in Punjab increased from an already intensive 140 percent to 188 percent (Singh, 2006).

The predominance of rice is especially remarkable, as almost no rice was grown in Punjab prior to 1950. Today, about 65 percent of gross cropped (35 percent of net sown) area is dedicated to rice (Johl, 2002). This cropping preference is in large part due to central and local government's economic incentives that specifically encourage the sowing of rice. These incentives include full economic offsets for electricity costs used in groundwater extraction since 1997 (excluding 2002 to 2005), which unsurprisingly exacerbated groundwater withdrawals; a minimum support price for rice, thereby enhancing its competitiveness; an effective procurement of rice, resulting in a risk free source of income and little to no government focus

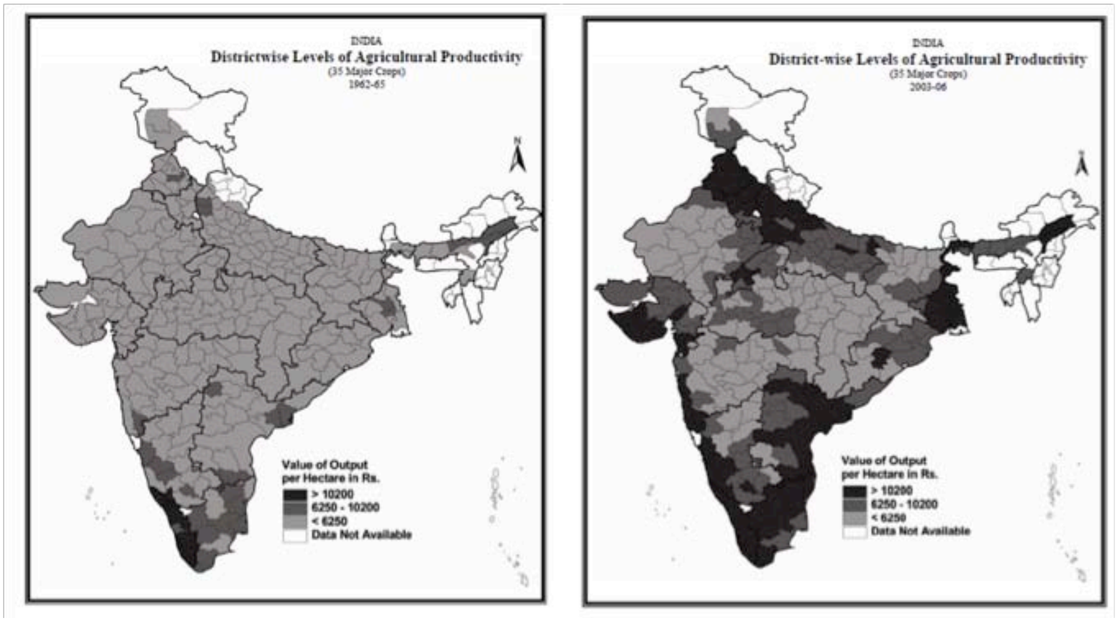


Figure 1. Districtwise levels of agricultural productivity during 1962-65 to 2003-06 in India for 35 major crops. (Source: Final Report of Planning Commission Project, Bhalla & Singh, 2010). This figure shows the growth in agricultural productivity for 35 major crops. Beginning in 1970s high yielding varieties (HYV) were also introduced. The uneven growth in food production, dominated by the irrigated northwestern states, is highlighted.

on other potential crop choices through procurement means or research. (Vatta and Siddhu, 2009)

The natural response of the farmers of Punjab to this lucrative price, secure crops, secure technology and high production was to bring more area under rice and wheat cultivation. As a result, cropping of less water-intensive non-cereal crops has declined. As seen in Figure 5, the agricultural area under cultivation for pulses (legumes) has shrunk from 22 percent in 1960-1 to 0.59 percent in 2006-7, even as the area under rice cultivation has grown from 5.57 percent to over 62 percent over the same time period. The area under wheat also increased from 34 percent to 82 percent. In 2006-07, the State contributed 60.9 percent of wheat and 30.2 percent of paddy in all India production.

A farmer survey conducted by CWC-PAU team supports the conclusion that farmer crop choices tend to be highly concentrated towards rice and wheat. In particular, farmers with larger landholdings have a larger share of their land under the rice-wheat system, as illustrated in Figures 6 and 7.

The dominance of paddy-wheat rotation has had a huge bearing on the pattern of water-use in agriculture in Punjab, transforming it from a water-surplus to a water-scarce state. The water application under this system approaches 2 to 2.5 m/year as compared to the regional rainfall of 0.5 to 1m/year. As early as 1985, the government of Punjab appointed an expert committee under the chairmanship of Dr. S. S. Johl to diagnose the problem of excessive groundwater irrigation and suggest suitable remedial measures. The Johl committee put forward the idea of diversifying agriculture away from the existing wheat-paddy cropping pattern toward production of less water-intensive but more remunerative crops such as fruit, vegetables, and pulses -- not only to increase income but also to reduce environmental degradation for the long-term

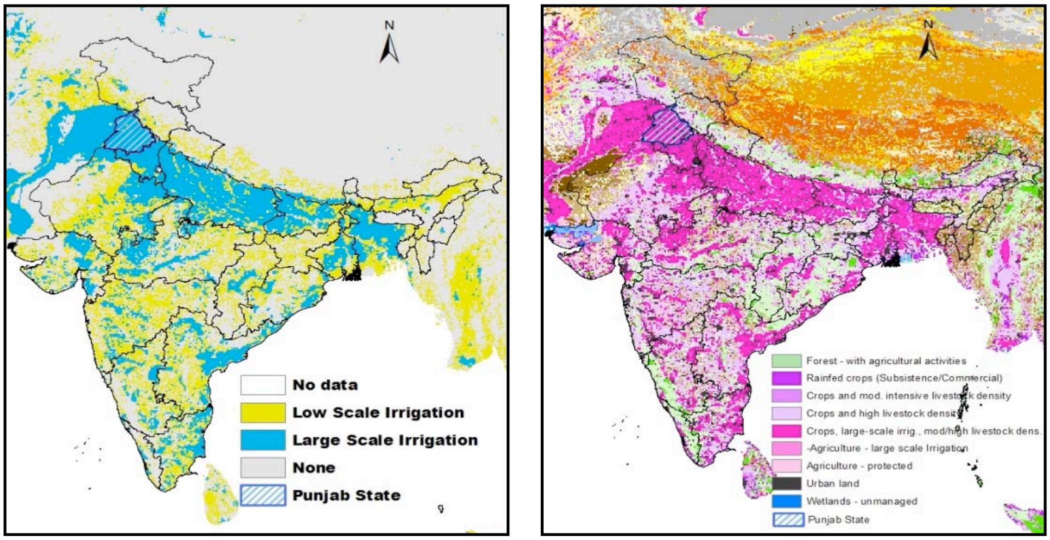


Figure 2. (a) Intensity of irrigation, and (b) land use map of India (the state of Punjab is highlighted as the shaded area in the North West) (source: FAO Geonetwork Data). The fertile alluvial plains running north to east have the highest intensity of irrigation in the country.

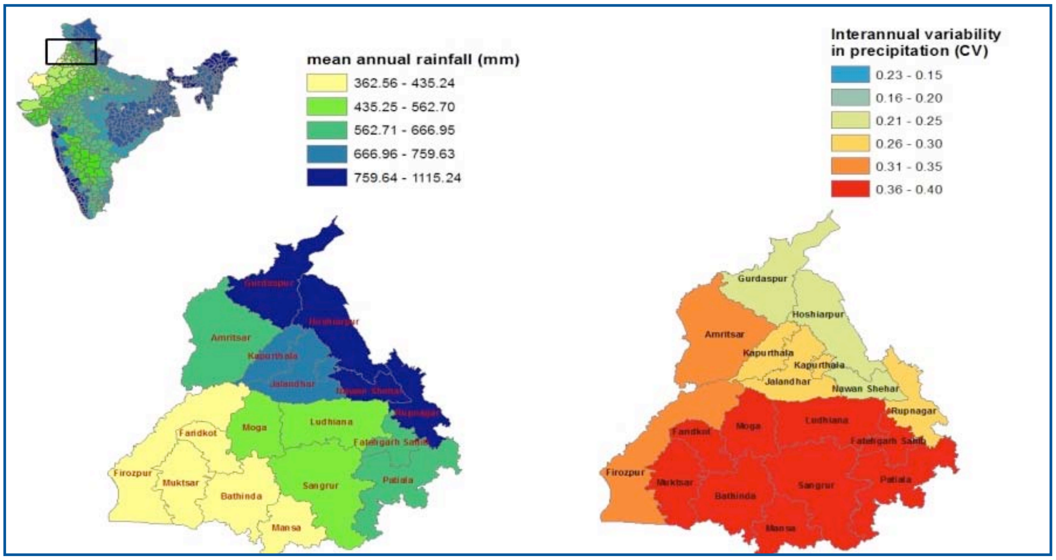


Figure 3. Spatial distribution of (a) Average annual rainfall in Punjab and (b) inter-annual variability in precipitation (red indicates highly variable)

sustainability of agriculture and water resources in the state (Government of Punjab, 1986).

Unfortunately, due to the economic and institutional advantages enjoyed by wheat and rice, government efforts to promote crop diversification since 1985 have been largely futile. On the contrary, the clear economic advantage of rice-wheat rotation

over other alternatives coupled with a risk free production environment has continued to push land away from other crops, reducing crop diversity. In 1975-76, the index of crop diversification was more than 0.75 during 1975-76 but fell significantly thereafter, reaching the current level of 0.58 (Statistical Abstract of Punjab, 2007).

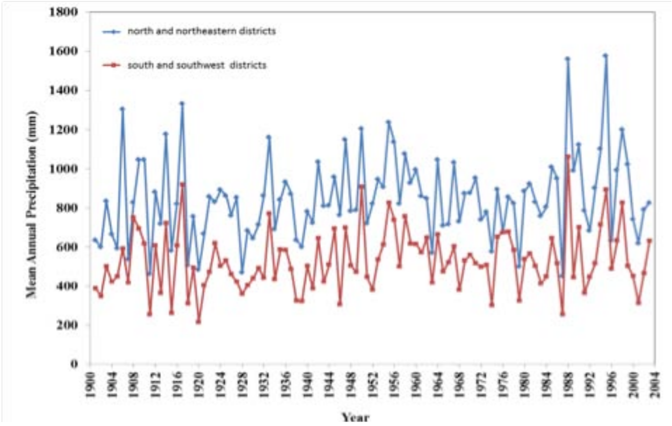


Figure 4. Temporal trends in mean annual precipitation in humid north & northeast (in blue) and semi-arid south/southwest districts (in red).

Despite the odds, in 2002, the Punjab government launched a crop-farming program aimed at removing one million hectares from the wheat-paddy rotation over five years as part of the diversification program recommended by the Johl Committee (2002) by partnering with private agribusiness to develop contracts with farmers. However, inclement weather, coupled with poor seed quality and insufficient farmer support from the government caused widespread crop failure. With no company willing to procure the produce, farmers were advised to sell on the open market. After this experience, a large majority of the farmers (60 percent) were unwilling to enter into contract farming arrangements again (Dhaliwal et al., 2003).

Energy subsidy and groundwater

In addition to several government subsidies supporting water-intensive cropping, pumping technology facilitated by subsidized or free power is responsible for the rapid expansion and overexploitation of groundwater resources in India (Planning Commission, 2007) (Figure 8). Free or practically free electricity has led farmers to use water irrationally, and over-irrigate their crops by using cheap, inefficient, poor quality motors – all of which have resulted in high energy use, mining of groundwater resources and a resulting decline in water tables. In Punjab, power for agriculture was totally free from 1997 to 2002 and from 2005 onwards, a subsidy benefiting farmers to the tune of Rs. 4320 million.

While the disadvantages of providing free electricity for irrigation have been well noted and documented, little has changed in the policy (apart from a nominal flat tariff imposed in 2009). The reason is political, as the existing policy is perceived to be friendly towards small and marginal farmers.

However, according to the results of the CWC-PAU

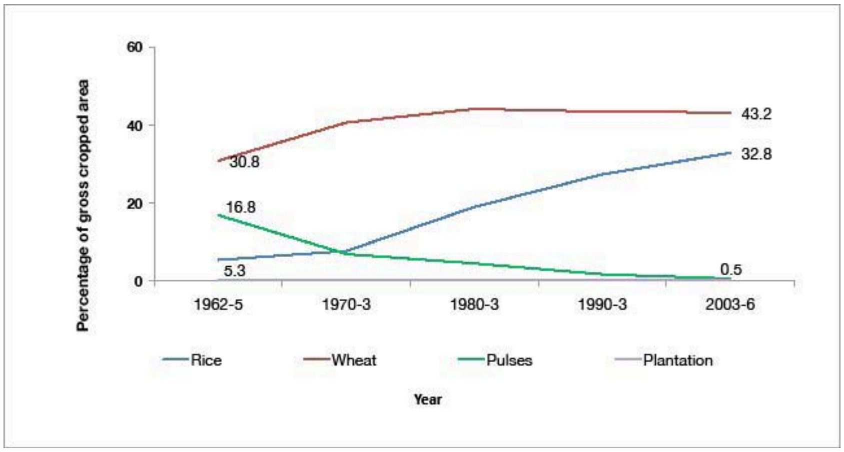


Figure 5. Changes in cropping pattern in Punjab between 1962-2006. The growth is rice wheat and pulses are shown as a percentage of gross cropped area (Source: Bhalla and Singh, 2010).

survey, farmers (whether large, marginal or small) are anything but satisfied with the current system, especially at it relates to power supply. An overwhelming majority of farmers questioned in the survey said they were dissatisfied with the quantity and reliability of power supply (95 and 85 percent respectively) (Fig. 9).

Furthermore, half of the farmers surveyed felt that voltage fluctuations were frequent, while 62 percent of the farmers have had their motors damaged at least once during the past 5 years as a result of voltage fluctuations. Seventy percent of farmers with larger land holdings reported greater damages compared to 54 percent of those with small landholdings, but this appears to be because larger farmers produce a less diversified crop mix, make more use of electricity and hence, are impacted more by the lack of quality and reliability of power supply.

In other words, while it may be true that large farmers are harmed more by the distortions and unreliability inherent in the current system, paradoxically this is only because they make more use of it and is thus more exposed to its weaknesses.

Declining Groundwater Levels

Since the 1970s, agricultural production in Punjab has grown steadily, with most of this growth dependent on increasing exploitation of groundwater for irrigation (Sidhu and Bhullar, 2005; Sharma and Ambili, 2010). Between 1970-71 and 2002-2003, the area irrigated by tubewells has increased by 81 percent, while canal irrigated area has decreased by 10.8 percent.

This trend of excessive groundwater drafting for agriculture has led to water tables dropping at an alarming rate; 79 percent of the groundwater assessment divisions (“blocks”) in the State are now considered ‘overexploited’ and ‘critical’ with extraction exceeding the supply (CGWB, 2010) (Fig. 10).

From 1982-87, the water table in Central Punjab was falling an average of 18 cm per year. That rate of decline accelerated to 42 cm per year from 1997-2002, and to a staggering 75 cm during 2002-06 (Singh, 2006). Water tables are now falling over about 90 percent of the state, with Central Punjab most severely affected (Figure 11).

Today, according to the latest annual report of the Central Ground Water Board and the Department of Irrigation, Punjab drafts 31.6 billion cubic meters (bcm) of groundwater every year. With an annual replenishable reserve of 21.44 bcm, the state overdrafts by a clearly unsustainable 45 percent.

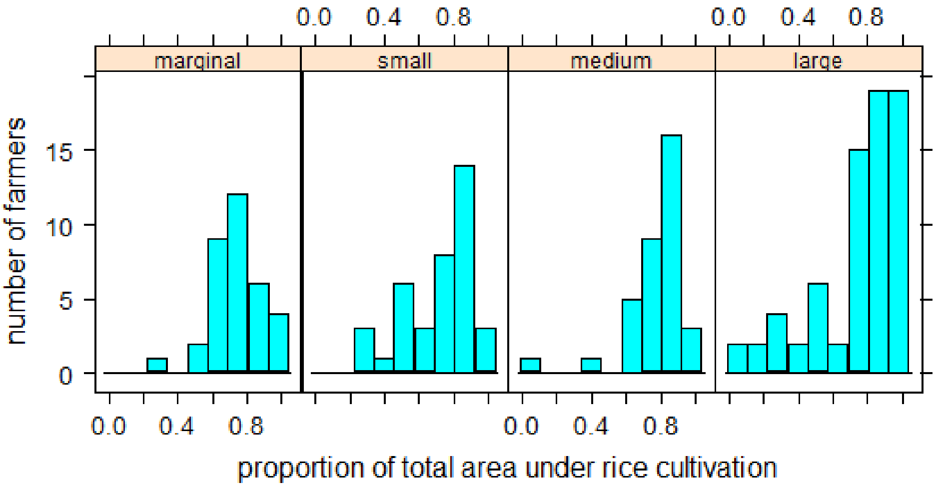


Figure 6. Proportion of cropped area under rice cultivation among surveyed farmers in Central Punjab, as a function of farm size.

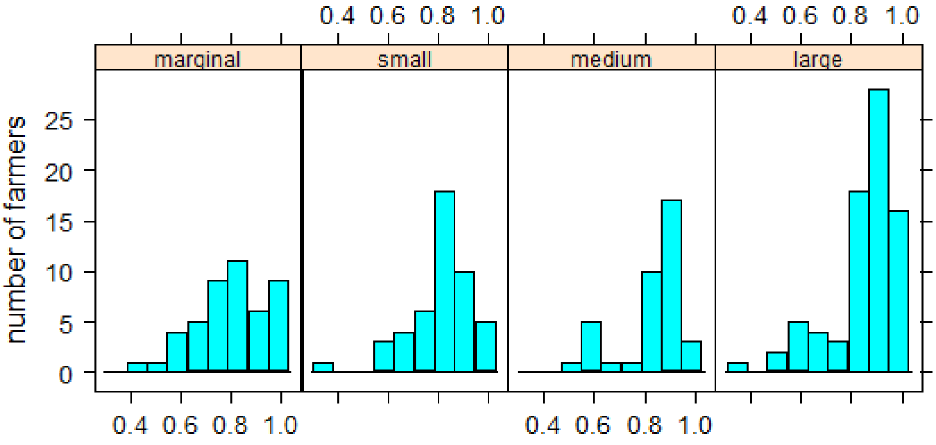


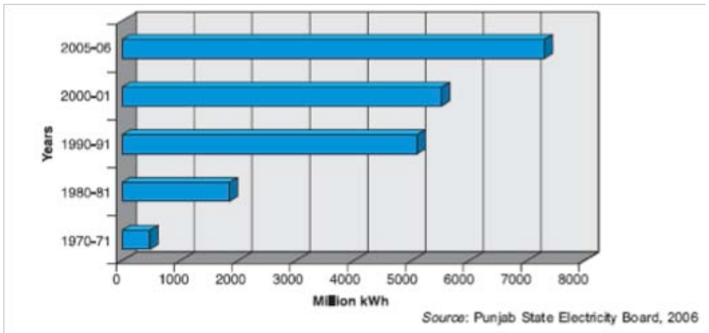
Figure 7. Proportion of cropped area under wheat cultivation among surveyed farmers in Central Punjab, as a function of farm size.

The rate of depletion averages about 0.4 meter per year in Punjab but locally can be as high as 1 meter per year.

Groundwater depletion has national implications as well, since as much as 70-80 percent of the value of irrigated agricultural output in India depends on groundwater irrigation (IRMED, 2008). Thus a large proportion of India's agricultural production as well as its GDP are tied to the availability of groundwater.

Further supporting the evidence of rapid groundwater decline has been the recurring need for farmers to deepen their irrigation wells over the years to reach water. In fact, 90 percent of farmers surveyed in Central Punjab reported deepening well at least once in the past decade, 55 percent twice or more and 20 percent three or more times (Fig 12).

An overwhelming percentage of farmers felt that decrease in rainfall over the past few years has been an important cause for the drop in groundwater table. In reality, however, there has only been a slight observed reduction in rainfall based on IMD data available to us, whose effects on recharge are likely to be small, relative to the observed drop in groundwater levels. On the other hand, a substantial percentage of the farmers surveyed felt that



Source: Punjab State Electricity Board, 2006

Figure 8. Consumption of electricity by the agriculture

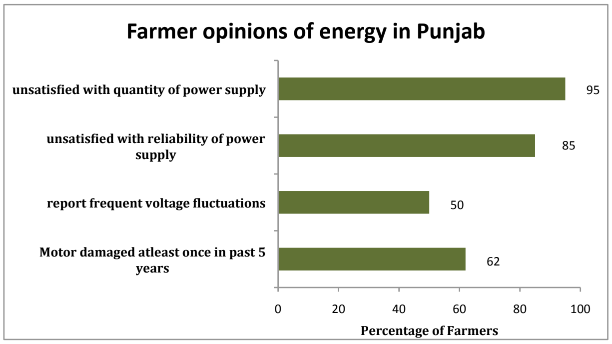


Figure 9. Surveyed farmers' opinion with regard to energy supply in Central Punjab.

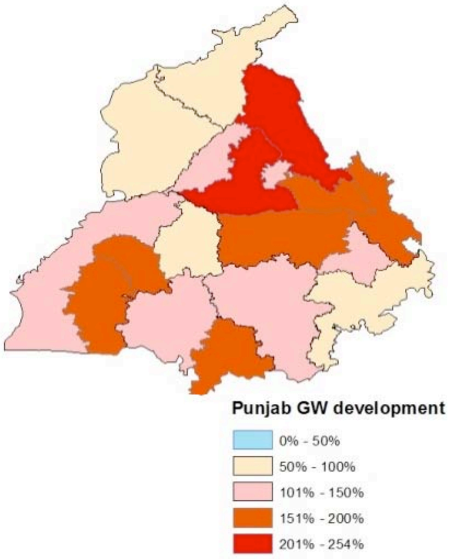


Figure 10. State of groundwater development.

increase in rice area was an important contributing factor, indicating significant farmer awareness of the importance of cropping patterns in determining irrigation demand.

Regarding efficiency of irrigation, there is widespread agreement at different levels that it needs to be improved. According to the Punjab State of the Environment Report (2007), the gap between irrigation potential and actual irrigation achieved needs to be bridged.

Seventy eight percent of farmers surveyed by CWC-PAU cited "awareness" and "practical issues" as matters of significant importance when it comes to improving water efficiency, as opposed to only 10 percent citing the "cost of implementing" a more efficient approach as an issue. A significant percentage of farmers (32 percent) were aware of more water efficient alternatives, but only 8 percent of farmers have actually used them.

The farmers surveyed connect the repeated deepening of wells, and the electricity reliability problems to the groundwater pumping for rice, and express a preference for marginal cost pricing of electricity if it is available when they need it (instead of at irregular times or at night) and for as long as they need it. In other words, they value reliability and will pay for it.

In addition, they are open to strategies for saving water in irrigation applications for rice, provided that they are reliable, cost effective, and do not impact the crop yield.

It is important to note that while the issues discussed above are relevant to the study project area of Central Punjab and many other semi-arid groundwater irrigated regions of India, water and irrigation problems may manifest themselves differently in other parts of Punjab and India. For example as seen in Figure 13 (blue areas), low lying pockets in southwestern districts of the state are

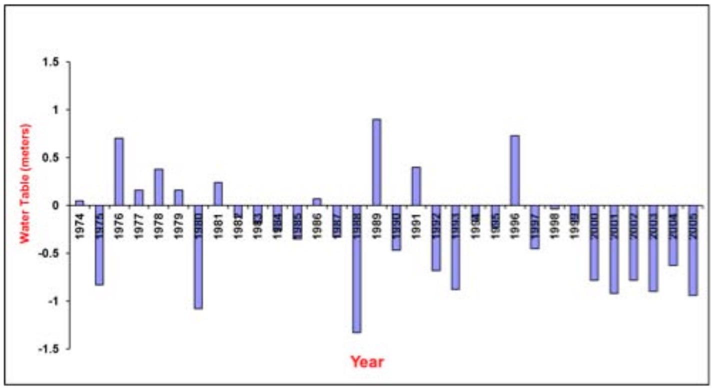


Figure 11. Year to year change in groundwater level in Central Punjab (1974-2005)

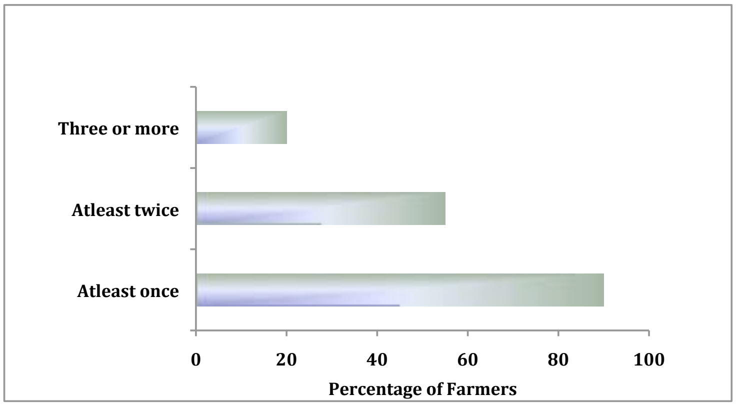


Figure 12. Frequency with which farmers deepened a well in the last 10 years in Central Punjab

facing a severe problem of water logging and resultant soil salinity that can be attributed to excessive canal irrigation, inadequate drainage systems and underexploitation of ground water resources due to salinity.

Due to the declining groundwater table in Central Punjab and the elevated saline groundwater in the south west, there are indications that sweet water has turned brackish due to reverse flow of saline groundwater from the south-western zone. Studies by the PAU have suggested that the proportion of this brackish water in Nihal Singh Wala block has gone from 11 percent in 1997 to 30 per cent in 2004 (Department of Soils, Punjab Agricultural University, 2006). This intrusion of semi-salty water into formerly sweet aquifers is both a serious concern for irrigated agriculture in the area and an indication of just how massive Punjab's groundwater mining operation has become.

Summary

The impact and significance of Punjab groundwater depletion is a national issue given the implications for long term food security. Regionally, the decline of groundwater quality linked to the depletion is a health concern. The poor reliability of the electricity supply contributes to a lack of industrial development. The state spending on the electric subsidy has nearly bankrupted the state budget, leading to a decline in education and health investments and outcomes. These factors provide a strong impetus for government action to correct the situation. However, while there is widespread recognition of these factors and what needs to be done to address them, there has been no movement on the political front, in part because the goals of the Central Government on food security and of the State Government to preserve groundwater and the environment are at odds. In terms of electricity pricing, an oft cited concern is that it is politically infeasible given the potential farmer reaction. However, our surveys show that depending on how this is done, and if reliable electricity is provided, there may be a way around this conundrum. The CWC is working with the Government of Gujarat on an ongoing field experiment for electricity pricing reform that has approximately 2000 farmers involved, about 800 participating in the scheme, and 1200 as control, so that the effectiveness of a specific pricing reform can be assessed. We hope to transfer this strategy to Punjab once the Gujarat

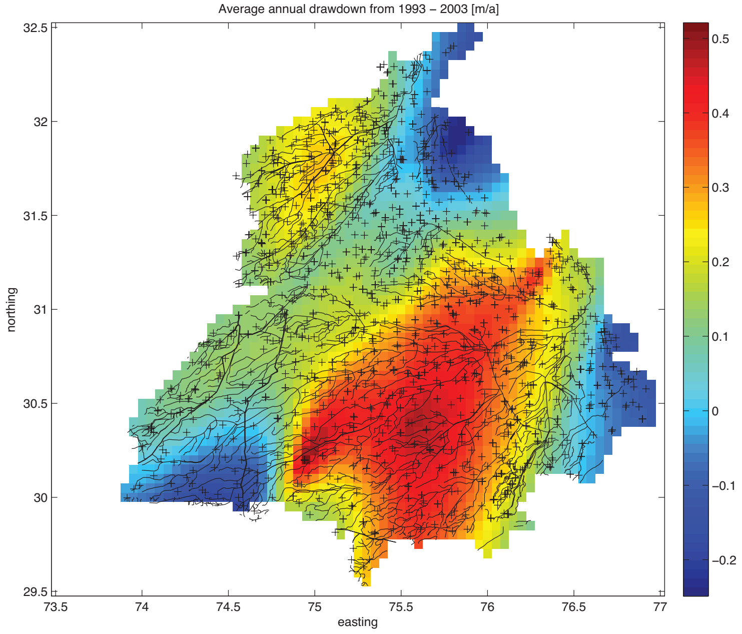


Figure 13. Average annual drawdown (Kriging interpolated from state managed observation wells) over the last 10 years [meter/year] in the state of Punjab (Source: Government of Punjab, 2006). The maximum drawdown is in red. It is important to take note of the fact that Central Punjab has 72% area under paddy cultivation, out of which only 21% has access to canal water irrigation. The tubewells in the central districts of the state constitute around 70% of total tubewells in Punjab, which have increased from 0.192 million (0.091 electric and 0.101 diesel operated) in 1970-71 to 1.168 million (0.880 electric and 0.288 diesel operated) in 2004-05 (Statistical Abstract of Punjab, 2005).

> Seventy eight percent of farmers surveyed by CWC-PAU cited “awareness” and “practical issues” as matters of significant importance when it comes to improving water efficiency, as opposed to only 10 percent citing the “cost of implementing” a more efficient approach as an issue.

experiment is completed.

Given the lack of political action towards addressing the problem in Punjab, the CWC-PAU team focused on the second major finding from the initial surveys with Punjab farmers, namely, the identification and scaling up of a strategy to save water with existing crops, that farmers are willing to adopt as a business model. A field experiment was conducted with 525 farmers in 2010, and extended to 5500 farmers in 2011. The lessons learned from the 2010 experiment are described in the next section.

TESTING SOME STRATEGIES FOR WATER SAVINGS

Given the difficulty of effecting large-scale policy reform to change subsidies for irrigation or guaranteed price support policies for rice and wheat, the CWC-PAU team formulated a two-pronged plan to explore and test ways to save significant irrigation water without any changes in government subsidies. On average, 1.8 m of irrigation water is applied for rice in Punjab, as compared to about 0.65 m for wheat. Consequently, if the same percentage savings were to be realized in both crops, the impact from savings in rice would be much greater. Consequently, the pilot focused on ***rice*** to begin with.

A significant percentage of farmers (32 percent) were aware of more water efficient alternatives, but only 8 percent of farmers have actually used them.

First, given that many farmers will continue the current cropping pattern, the project looked for the best and most cost-effective technologies or practices to grow rice using less water (more crop per drop).

Second, the project looked at ways to help farmers transition from the current water and energy intensive rice-wheat system to a less water-intensive crop rotation without increasing their income risk. By growing high-value vegetables instead of rice, for example, farmers could save substantial quantities of water while increasing their income; by partnering with agribusinesses farmers can be offered contracts that mitigate the greater risk of loss from these crops. Models of contract farming as a strategy to save irrigation water will be discussed in a later paper.

Technologies and Practices Designed to Save Irrigation Water

Over the years agronomists have developed a variety of technologies and practices designed to conserve irrigation water. A number of these have been researched in India (Vatta and Siddhu, 2009). By reducing the use of irrigation water, these water-saving approaches not only improve water use efficiency, they also help maintain soil structure, enhance soil fertility, reduce the system's chemical load and reduce soil erosion. However, many of these technologies and practices are yet to be field tested at a scale to demonstrate the potential for consistent water savings, and the CWC-PAU farmer survey showed that *few farmers in Punjab have adopted them to date, or are aware of them*.

In order to lay the groundwork for field-testing new water-saving approaches, in 2009-10 the CWC-PAU team recruited farmers through an outreach campaign involving multiple field agents in 5 districts of the State. In addition, the team inaugurated "Punjab Water Day," on March 20, 2010, an event designed to shift the focus from water development to water management and to call attention to Punjab's water crisis while highlighting potential responses. The discussions were meant to raise farmer awareness about the benefits and potential of changing water use patterns to reverse the crisis of dwindling surface and ground water reserves in the region and to encourage reducing energy use while maintaining crop yields and income (Fig 14).

Along with follow-up activities (Fig. 15), the event led to the identification and recruitment of 525 farmers from 5 districts in central Punjab who agreed to participate in field trials of water-saving technology. Some of the options evaluated by the

CWC/PAU team for large-scale field-testing include laser leveling, direct seeding of rice and tensiometers.

Laser Leveling

Studies have shown that unevenness of fields can be responsible for significant (20 to 25 percent) irrigation losses due to puddling and high soil evaporation. The problem is particularly pronounced for rice fields, which experience frequent flood irrigation. In addition, unevenness of the surface has a negative impact on the germination, stand and yield of crops. Fields that are not level have increased weed burdens and uneven crop matruration.

Laser leveling allows farmers to grade their land with a high degree of precision, reducing runoff and evaporation losses from puddling. The technology involves using tractors equipped with laser-guided instruments to smooth the land. It is a proven approach that has long been regarded as highly useful in conservation of irrigation water.

However, laser-leveling equipment is relatively expensive and requires training to use. Because the CWC-PAU team was looking for the most cost-effective and easily adopted approach to saving water, the project did not promote laser leveling in its first year. However, many of the farmers recruited were already using the technology. This allowed the team to study the effectiveness of the practice, especially in conjunction with other approaches.

Direct Seeding of Rice

In conventional rice cultivation, farmers start seedlings in a small part of their fields (the nursery); when the seedlings have matured, they are transplanted into standing water in the field. While this practice helps to suppress weed growth and provides good yield, the need to flood fields raises serious concerns about the long-term sustainability of growing rice, particularly in water-stressed regions such as Punjab.

By contrast, direct or dry seeding of rice involves sowing seeds directly into unpuddled soil. While these fields are irrigated over the course of the season, the crop is not kept in continuously standing water, thus saving a significant amount of irrigation. The practice is not new, but has not yet taken hold on a large scale.

Direct seeding is not without problems, however. Without standing water to keep weeds at bay, most farmers use large amounts of weedicide, leading to concerns about both the ecological health of fields and the effect of pesticides in the food chain. An alternative is hand weeding, but this adds labor costs.

To study the potential water-saving effects of direct seeding, the project team distributed seeds to 75 farmers in the Amritsar, Sangrur and Ludhiana districts. The targeted farmers were asked to try direct seeding on one acre of their land; the remainder of their land was planted as usual.

Unfortunately, results from the direct seeding experiment were inconclusive. Because the practice is so different from conventional cultivation, relatively few farmers were willing to take on the perceived risk of trying it. In contrast to using tensiometers, whose use can be abandoned at any time, direct seeding of rice requires farmers to commit to the process for an entire season, causing many to hesitate to try it.

In addition because of an unusually wet year (with 30 percent more precipitation than normal) with significant early rainfall, seeds in 35 fields *did not germinate* as expected. Consequently, only 60 percent of the farmers recruited for the experiment completed it, while the remainder either plowed the field under or transplanted. Farmers also reported that the direct seeded rice appeared to have

Figure 14. CWC Director, Prof. Upmanu Lall addressing the World Water Day event

Figure 15. Faculty, researchers and soil scientists at the CWC -PAU meeting with the village heads and farmers on water saving technologies on their farms.1

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1 Pictures for the Punjab project and trips are available at http://www.flickr.com/photos/columbiawatercenter

smaller grain development, causing them to fear lower yields. Problems were worse for farmers with sandier soils.

Nonetheless, the farmers who completed the program reduced water consumption significantly, with the highest number of irrigations saved in Sangrur and lowest in Ludhiana (Fig. 16).

The Tensiometer – *An Inexpensive Method to Save Irrigation Water*

Tensiometer technology dates from the early years of the 20th century. The device typically consists of a sealed, water-filled tube with a ceramic porous cup and a vacuum gauge at the top; the device is designed to provide an estimate of soil moisture. As soil moisture decreases, the water level in the tube goes down. If the indicated soil moisture is lower than the desired level for a crop, the farmer needs to water. By taking the guesswork out of irrigation, the device allows farmers to water only when needed, thus saving water and promoting better crop health. Costing between $40 and $200 however, conventional tensiometers are out of reach for most farmers in the developing world.

To address this problem, several years ago Dr. Kukal, a scientist at the PAU, developed a simpler, more affordable tensiometer that cost only $7. The scientists accomplished this in part by replacing complex gauges with three bands—red, yellow and green—to indicate when a crop should be irrigated. By calibrating the tensiometer for a specific crop (in this case rice) they were able to produce a device that was not only substantially less expensive than the conventional alternatives but also easy for farmers to use.

Of the technologies and practices studied in the first phase of the project, the tensiometer quickly emerged as an effective, cost-efficient, easily adopted and low-risk approach to save irrigation water. The application results for the experiment in the five districts of Punjab illustrated in Figure 16, are presented next.

Water Savings by Farmers Using Tensiometers

Conventional rice cultivation involves sowing rice into a small nursery field; when they are ready, rice seedlings are transplanted into standing water. These fields are then kept flooded throughout the growing season--a practice that essentially involves use of large volumes of irrigated water – and which most often precludes any forethought on efficient water usage practices.

As a result, crop irrigation follows neither scientifically nor economically optimal water use patterns. In addition, farmers are under the impression that more water inherently provides higher yields, though the empirical research and field level evidence do not support such a belief (Sidhu et al., 2007). In reality, the actual water requirement of the rice crop is much lower than the amount of water farmers usually apply.

PAU teams took tensiometers to each of the 525 farmers and installed them in an approximately one acre plot that would be designated for the test. Farmers were asked to water that portion of their crop according to the tensiometer readings, and water the remainder of their fields as they had previously.

Promising Results

Eighty five percent of the farmers who were initially recruited in 2010 followed through with the entire experiment. Of these, all reported consistently good results and indicated their intention to convert their full operation to tensiometer use in the next cycle.

Farmers who completed the trial reported an average of 22 percent water savings over conventional methods, as illustrated in Table 1.

Figure 16. Experimental CWC-PAU field study sites for implementing cost-effective water saving technologies in Punjab (5 districts involving 525 farmers)

Farmers who did not follow through with the trial pointed to technical difficulties and excess rain as the primary reasons. Technical problems imply some failure of the tensiometer which will be rectified in future applications of the technology.

Regarding excess rain, 2010 turned out to be an unusually high-rainfall year, meaning that farmers' irrigation needs were significantly reduced across the board and farmers were less inclined to closely monitor their irrigation needs. High rainfall is also likely to have reduced average water savings from tensiometers as the number of irrigations was substantially reduced.

Reasons for the 15% of farmers who did not complete the experiment were solicited and resummarized in Figure 17. Twenty three percent of the non-follower farmers dropped out because they were not interested and 9 percent dropped out due to lack of adequate follow up by extension agents.

> Of the technologies and practices studied in the first phase of the project, the tensiometer quickly emerged as an effective, cost-efficient, easily adopted and low-risk approach to save irrigation water.

Given the feedback from post-season interviews, the team expects that 60 percent of the non-followers can be recruited in Phase II[1].

Patterns in Yield and Water Savings

As shown in Figure 18, using tensiometers for rice farming in central Punjab resulted in substantial water savings. Very few farmers saved less than 10 percent, in spite of a very wet year. A large majority of the farmers had savings which exceeded 20 percent of seasonal water use. Given that farmers plant different varieties of rice and were in different districts, the team also examined whether any of these factors were associated with substantial differences in water savings.

Figures 19 and 20 indicate water savings by variety of rice and district, respectively[2]. It was found that Pusa-44 was associated with lowest water savings and basmati was associated with most[3], while there

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[1] Phase II, conducted in 2011, focused on a rapid scale up of the number of participants.

[2] The dark black line is the median, and the "whiskers" are 1.5 IQR, where IQR is the "inter quartile range", defined as IQR=p75-p25 i.e. the distance between the 75th and 25th percentiles. Data points beyond the whiskers are traditionally thought of as "outliers".

[3] A caveat is the very small sample size for

Table 1. Results of Tensiometer experiments from 525 farmers, applied to an approximately 1 acre plot and compared with an application of conventional methods (fixed frequency and depth of irrigation) over the balance of the plot.

Mean water savings per acre (%age)	22
Mean water savings	419062 (litre per acre)
Mean (%age) increase in yield	1.05
Mean (%age) reduction in energy usage	24 (per acre)
Mean reduction in energy usage	90 (Kwh per acre)
Total savings in energy (in Kwh)	36081 (in Kwh)
Monetary savings in energy (in monetary values)	@ Rs 4.15 per Kwh = Rs 149,736

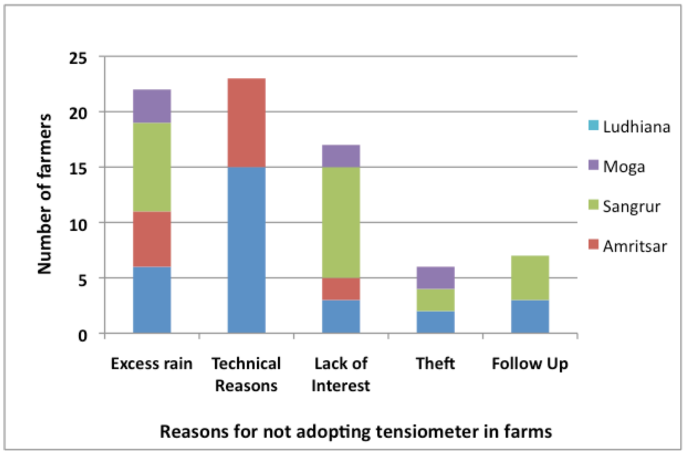

Figure 17. Reasons cited by farmers for not adopting tensiometer

was little difference between non-basmati and non-Pusa rice (labelled as “other rice”). There was greater difference in water savings across districts, with the highest median saving (30 percent) associated with Amritsar and the lowest (20 percent) in Moga district. Nonetheless, these differences are not substantial, and may be explained by differences in crop varieties[4] or other factors, especially changes in water levels[5].

Changes in yield were relatively small across all crops and districts, as indicated in table 2 below, in all varieites of rice, and all districts except for Sangrur, which saw a marginal drop in yield. Most importantly, the field study shows that yield was rarely reduced as a result of using the tensiometer, and then only by small amount.

Energy saving Distribution

Results of the project showed that tensiometer usage saved significant amounts of energy as well. As Figure 22 indicates, a large majority of farmers using tensiometers reduced their energy consumption by at least 60 kwh per acre, with a distribution of savings by crop variety and district that parallels

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basmati (17), which makes any comparison with other varieties difficult.

[4] The very small sample size precludes the obvious strategy, of computing and plotting savings in water use by district-crop combination. Further, (in our sample) there is no cultivation in Amritsar district of Pusa-44 while districts other than Amritsar do not cultivate basmati.

[5] There is little variation in the water levels themselves, as a result of which we do not present a distribution of water levels by district and crop.

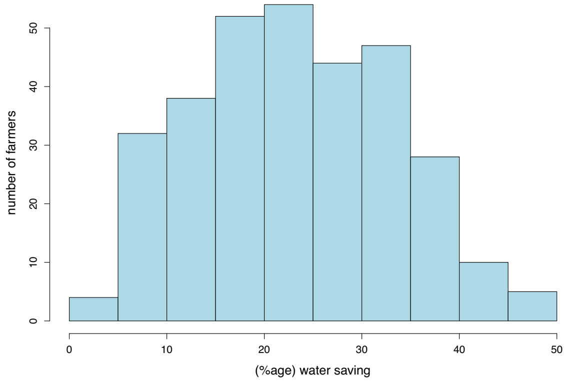

Figure 18. Histogram of percentage water saved (relative to the control) by the intervention

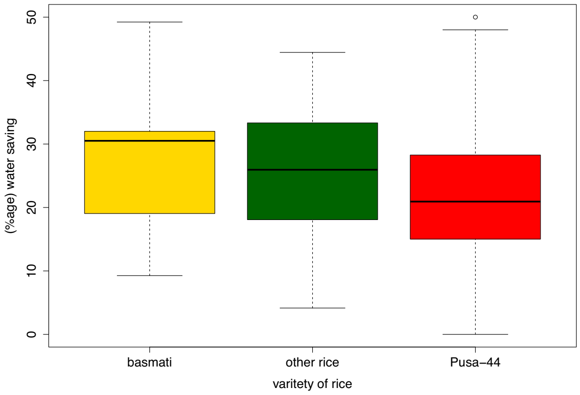

Figure 19. Percentage water savings by variety of rice

that of water.

It should be noted that both water savings and energy usage are impacted by changes in rainfall patterns. Because the year 2010 was much wetter than usual, farmers used substantially less water use in both control and treatment plots. Any findings in terms of water savings may thus be viewed as a lower bound of possible savings in any given year.

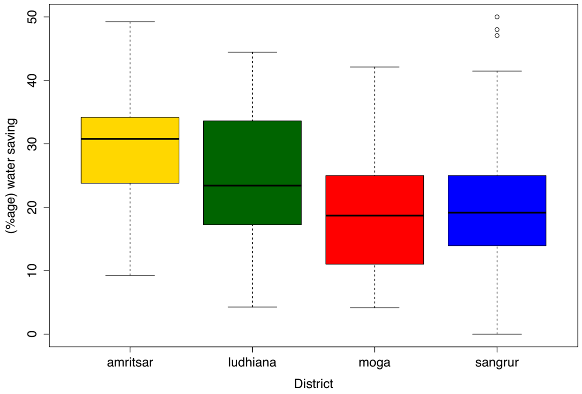

Figure 20. Percentage water savings by district

Summary of some of the factors

Based on the field results from 2010, it is shown conclusively that tensiometers helped rice farmers in Punjab save a large amount of water, even in a less-than-optimal year for testing. Additionally, farmers were willing to adopt tensiomerers in their fields, which indicates the willingness on the part of community to save water. These results suggest that a rapid scale-up of this technology could save a truly significant amount of water and energy in Punjab, and thus play a critical role in stemming or reversing Northwest India's groundwater depletion crisis.

However, it is important to understand that there is no "one-size-fits-all" approach to saving water. Results from the CWC study suggest that there are substantial variations in water savings and yield changes from the use of tensiometer across different farmers. Understanding the factors and circumstances behind such differences is important in order to continually refine and promote a robust approach to scaling up the use of the technology—to find, in other words, the most appropriate and effective situations in which to apply tensiometers and thereby maximize its benefits across the state

Table 2. Changes in Rice Yields under tensiometer use in paired experiments.

(%) Yield change	District
1.02	Amritsar
3.6	Ludhiana
0.95	Moga
-0.9	Sangrur
	Rice Variety
0.42	Basmati
0.7	Pusa-44
1.38	Other rice

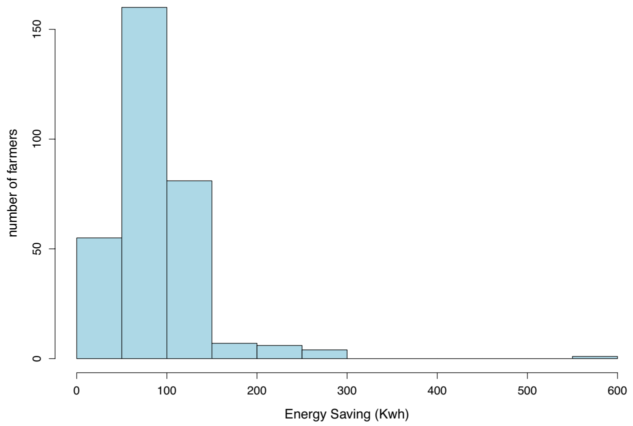

Figure 22. Energy saved (in Kwh)

and beyond.

Because energy for irrigation is subsidized in Punjab (as it is in most of India), farmers do not pay for the marginal cost of overwatering and therefore have little immediate incentive to conserve. However, farmers do suffer from falling water tables that require them to dig expensive ever-deeper wells, as well as from unreliable electricity supplies that result from the stress excessive irrigation places on utilities.

Therefore, it is plausible that only those farmers who experience either a (relative) shortage of electricity or a substantial decline in water levels are likely to make the added effort to make use of the tensiometer, while others who do not experience shortages may be less motivated or interested using the technology. It is also plausible that farmers who are more highly indebted would be more motivated to minimize the costs of production and therefore put more effort into reducing water use than those who are otherwise similar but have smaller debt levels. These factors can be inferred in various ways, from self-reported water levels (to identify farmers who are suffering more from depletion) to number of tractors or machine implements (suggesting greater indebtedness).

To test these hypotheses, the project team collected additional information from farmers, including values of self (farmer) reported changes in water levels,[6,7] the presence and number of tractors and supplemental diesel generators for irrigation and the presence or application of other water-saving activities. In order to empirically uncover any such interesting behavior, the team adopted a regression-based approach for further exploration.

Some results were surprising: for example, tensiometer-using farmers who had their fields laser-leveled as well actually experienced a slightly smaller water savings than those who used tensiometers alone.

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[6] Change in water level is measured as the difference between water levels today and that of 5 years ago.

[7] We ignore the bias induced by the fact that only farmers who have experienced significant decline in groundwater levels are likely to either provide the figures or to provide accurate figures. This bias is unlikely to be large in such a sample where farmers were asked in detail individually about water levels.

Table 3. Per season electricity cost savings as a function of motor horsepower per hectare of rice planted in Central Punjab, assuming a 2010 electricity price of Rs. 4.15/kwh. Compare these numbers with an annualized cost of tensiometer of Rs 170, assuming a 3 year life, 10% failure rate, and an initial cost of Rs 500.

Motor Horse Power	Water Saving (liters)	Motor Hr Equivalent Savings	Electricity Cost Savings (Rs)
5	4500000	179	2764
7.5	4500000	179	4146
10	4500000	104	3225
12.5	4500000	104	4031
15	4500000	83	3870
20	4500000	73	4553

On the other hand, farmers who owned supplemental diesel generators seemed to save significantly more water when compared to those who didn't—possibly because these same farmers had experienced problems with electrical supply or declining water tables and were more motivated to save water.

By continuing to explore and analyze factors relating to differences in amount of water saved under different circumstances, the project team will be able to continually refine the approach to scaling up use of tensiometers, thus making the application of this technology more robust and effective.

DISCUSSION, IMPLICATIONS AND NEXT STEPS

Several government programs already exist in India to promote adoption of new water saving technologies such as drip or sprinkler irrigation. However, despite their promise these technologies have not yet had a transformative effect. Even in the United States, drip accounts for less than 10% of the irrigation practice, and is largely used in orchard and vegetable settings, while flood irrigation still accounts for nearly 50% of the fields. In conjunction with changes in cropping patterns, any effective water saving program needs to promote the development and testing of a financially viable business model that not only leads to the adoption of appropriate, crop-specific irrigation technologies but also benefits both the State and farmers. In this context, it is instructive to examine the financial implications, as illustrated in Table 3. Motor Horsepower used in Punjab varies between 5 and 20 HP, as indicated. The table indicates savings of between Rs 2764 and 4553 per season vs an annualized cost of Rs 170, an excellent rate of return!

CWC estimates that if 60 percent of farmers across Punjab adopt the tensiometer and achieved an average water savings of greater than 25 percent, the technology could help the state achieve a significant reduction in and potentially a reversal of groundwater depletion, at very low cost. In fact, the energy cost savings alone could easily pay for the technology. At current rates, total energy savings per season would be Rs 1.615 billion ($36 million)

compared to an initial one-time investment of approximately $28 million in tensiometers.

For 2011, the CWC/PAU team has expanded the tensiometer project, recruiting over 5,500 farmers to participate in the next level of testing. Results of this expansion will be available soon. The success of 2011's recruiting process alone suggests that farmers are eager to try this new approach, seeing much potential benefit in its application and little or no downside, and there is every reason to believe that enthusiasm for the device will continue to grow quickly.

Beyond Punjab, the CWC is working with farmers and government officials in the state of Gujarat to save water there as well, using tensiometers (calibrated to for wheat production) in conjunction with a suite of other water and energy-saving technologies.

In Gujarat, the project also incorporates an energy incentive pilot initiative structured to save both the farmer and the government money, while also reducing water use and energy cost. Coupled with these incentives and the other technologies, the tensiometer becomes an important part of a robust set of tools for water savings, as well as providing a potential model for an integrated approach that could be used to save substantial amounts of water as well as energy in Punjab and other parts of India.

Ultimately, to stem or reverse India's groundwater crisis, an integrated approach that looks at the multiple factors involved in saving irrigation water--including crop substitution and reallocation, incentive reform and partnership with corporate food producers to ensure farmer incomes, as well as more water-efficient cropping using technologies such as the tensiometer—are both necessary and possible.

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