Water-Saving in Agriculture

A Roadmap to ICID Vision 2030

ICID•CIID

International Commission on Irrigation and Drainage (ICID)

Water-Saving in Agriculture – 2020

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International Commission on Irrigation and Drainage (ICID), established in 1950 is the leading scientific, technical and not-for-profit Non-Governmental Organization (NGO). ICID, through its network of professionals spread across more than a hundred countries, has facilitated sharing of experiences and transfer of water management technology for over half-a-century. ICID supports capacity development, stimulates research and innovation and strives to promote policies and programs to enhance sustainable development of irrigated agriculture through a comprehensive water management framework. The mission of ICID is to stimulate and promote the development and application of the arts, sciences and techniques of engineering, agriculture, economics, ecological and social sciences in managing water and land resources for irrigation, drainage, flood management, for achieving sustainable agriculture water management.

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FOREWORD

Water is essential for life and development, and it is not a surprise that it is a central to several UN-Sustainable Development Goals, SDGs. The frequently occurring water-scarcity situations around the world due to climate change and population growth compel us to look for new ideas to produce more food from less water. In other words, increasing Water Use Efficiency, and Water Productivity. We are all realizing that science-based innovations do work and provide solutions to improve human life. ICID as a leading scientific and technical organization has been playing a critical role in enhancing national capacities of its members to use agricultural water more judiciously so that food is produced with less water and subsequently, more water becomes available for use in other sectors of the economy.

ICID members and partners clearly recognize that, the problem is not only a water crisis due to population growth and climate change but also a water mismanagement crisis. Traditional flood irrigation practices have to be transformed into smart, precise and more efficient water management systems. The WatSave Awards program is one such example to demonstrate ICID's resolve to tackle the wasteful use of water in the agricultural fields around the world. Since its actual inception in 1998, the WatSave program has attracted the attention of the best of applied research minds working in National Institutes, Universities, Research Centres, NGO's, Ministries, Industries, and farm fields. The efficient technologies and effective scientific management approaches profiled in this publication have emerged as the two main areas of interventions to make water saving in the agricultural Sector.

The National Committees of ICID launched in principle the WATSAVE Initiative in late 1993 and started giving awards since 1998. The ICID network has responded magnificently and rapidly transformed into a unified global force to meet the challenges of water scarcity and climate change impact against increasing demand for food. Through WatSave program, each year ICID member National Committees and related groups report billion cubic meters (BCMs) of water saved in their regions that became available for either increasing irrigated area or for other uses such as industry, tourism, leisure and domestic.

Technologies are generally local and scale-specific, and their transfer to new areas requires the right scaling. Technology adoption by farming communities has several other issues that also need holistic planning, such as technology financing options, enabling government policies, capacity building and proper consideration of the socio-economic conditions of farmers, particularly the smallholders.

Technological innovations backed by the right management practices can significantly increase the amount of water saved or the number of beneficiaries in a particular context or setting. However, certain management interventions may only apply to large-scale irrigation schemes or require system changes. Resource requirements widely range from an accurate estimation of water needed for a crop field to enhancing institutional and human capacities.

Finally, I would like to thank all the WatSave Award winners who submitted their research findings through their National Committees for consideration of the International Panel of Judges (PoJs) that selects the winning entries using a well-defined criterion. My thanks also go to the other nominees who most of the time finish at close second. The famous quote of Thomas Edison "Genius is 99 percent perspiration and 1 percent inspiration", justifies the efforts of all nominees to be included in this publication. We must all also appreciate the voluntary contributions of all the members of PoJs, WG-WATS, and NCs in helping ICID run the WatSave program smoothly despite the fact that the number of nominations is increasing every year. I hope this publication would be globally useful for greater adoption of efficient water use and effective agricultural water management for overall sustainable development.

Prof. Dr. Ragab Ragab
President, ICID

PREFACE

Policy advocacy, technology development, capacity building and knowledge dissemination are at the core of the ICID network for the past 70 years. This publication is in a way to celebrate the 7-decade existence and relevance of ICID which started with a handful of members and has grown to represent more than 90% of the world irrigated area. Professional networks outlive the individuals associated with them because they propel good ideas from one generation to the next and this publication is all about good ideas to save water in the agriculture sector.

With its vision "water-secure world, free of poverty and hunger through sustainable rural development", the International Commission on Irrigation and Drainage (ICID) launched its global water-savings (WatSave) program by forming a WatSave Work Team in the year 1993 to promote and recognize water-saving technologies and management practices across the world. The WatSave Work Team proposed to institute the ICID WatSave Awards with the primary focus on water conservation success stories of the ICID member countries. Accordingly, a booklet providing generic information about the water saving practices adopted by some of the ICID member countries was published in 1995. Later, the booklet entitled "THE WATSAVE SCENARIO" comprising information received from 27 member countries was published in 1997. These documents were very well received not only by ICID member countries but also by international organizations, as well.

Subsequently, since 1998, the WatSave Awards have been presented each year to recognize globally outstanding contributions to water conservation or water-saving in agriculture under four categories: Technology, Management, Young Professional, and Farmer(s). The Awards given to individuals, or a group of individuals are made regarding "actual realized savings" and not for promising research results, plans under consideration, or theoretical intentions to save water. From time to time, the award criteria have been modified to suit the prevailing knowledge practices.

To celebrate 60 years of ICID foundation, a book publication titled "Water-Saving in Agriculture" was released by ICID in 2008. This book synthesized and provided summary information on successful water-saving case studies from Australia, Brazil, China, India, Egypt, Korea, Pakistan, South Africa, Spain, Turkmenistan, and the USA. It also highlighted that water-saving efforts are more visible in countries having significant area under irrigated agriculture. The innovative ideas and practices captured in this publication of 2008 were also aimed to enthuse other countries and ICID's mission to spread 'best practices' showcased in the book.

Compiling the innovative nominations of newer technologies and management practices since 2008, this serial publication demonstrates the outcome of the initiatives of ICID members towards encouraging interventions for water-saving in agriculture. Individual successful technologies and management practices, developed by individuals, institutions, NGO's, farmers, and the stakeholder community at large, which resulted in water-saving from across the world, are presented in a brief case-study form. The global issues and challenges in the water sector and international perspectives on water savings in different geographies have also been discussed.

While bringing out the contributions made toward water-saving techniques and technologies, efforts have been made to integrate these contributions concerning contemporary issues such as climate change, agronomic practices, agroecology, and the environment. The activities conducted towards the fulfilment of ICID's vision and contributing towards UN Sustainable Development Goals have been briefly analyzed while providing technical details of the nominations received by ICID for deciding upon the WatSave awards through a panel of judges comprising of global water experts. With increasing stress on available water resources further exacerbated by potential effects of climate change, we feel that the techniques and technologies presented here will go a long way towards more sustainable agriculture and food, fibre and energy production for the global communities.

During 2008-2020, a total of 105 nominations were received by ICID in different categories of the Award and they are all profiled in this publication. Technology and management are the two main themes of this compilation.

Lastly, I wish to thank all, including researchers, engineers, managers, young professionals, farmers and others who submitted their innovative work to the ICID WatSave program. Our thanks are also extended to the Panel of Judges which evaluated all these nominations over the successive years to select winners of the Award. Chair and members of WG-WATS reviewed the manuscript, and it is highly appreciated. Thanks, are also due to Ms. Prachi Sharma, Knowledge Officer and Dr. Sahdev Singh, Director (Knowledge Management) of central office for painstakingly collating the distributed information and preparing the publication.

Er. Ashwin B. Pandya
Secretary-General, ICID

ACKNOWLEDGEMENTS

WATSAVE AWARD WINNERS

ICID recognizes and expresses sincere thanks to the WatSave Award winners in different categories since the program inception till date.

(A) INNOVATIVE WATER MANAGEMENT AWARD

Sl. No.	Name of Winner(s)	Country	Year
1	Mr. EL Bouari Ahmed	Morocco	2021
2	Mr. Mahdi Afsari	Iran	2020
3	James Winter & Tony Quigley	Australia	2019
4	Mr. Richard Phillips	Canada	2018
5	Prof. Wang Aiguo	China	2017
6	Mr. Va-Son Boonkird & Dr. Watchara Suiadee	Thailand	2016
7	Prof. Samiha Ouda and Prof. Abd-El- Hafeez-Zohry	Egypt	2015
8	Dr.Yosri Ibrahim Mohamed Atta	Egypt	2014
9	Mr. Zhang Xuehui	China	2013
10	Mr. Peter McCamish	Australia	2012
11	Prof. Dr. Subhash Madhawrao Taley	India	2011
12	Mr. Kobus Harbron	South Africa	2010
13	Messrs Shahaji Manikrao Somawanshi, Bharat Kawale and Sanjay Madhukar Belsare	India	2009
14	Dr. Yousri Ibrahim Atta	Egypt	2008
15	Dr. Abraham Singels	South Africa	2007
16	Dr. Nico Benadé	South Africa	2006
17	Prof. Li Daixin	China	2005
18	Er. Suresh. V. Sodal	India	2004
19	Dr. Muhammad Akram Kahlown	Pakistan	2003
20	Dr. Mahmoud Moustafa	Egypt	2002
21	Prof. Gu Yuping	China	2001
22	Dr. Francisco del Amor Garcia	Spain	2000
23	Eng. Hussein El-Atfy	Egypt	1999
24	Prof. Wu Xijin	China	1998

(B) INNOVATIVE TECHNOLOGY AWARD

Sl. No.	Name of Winner(s)	Country	Year
1	Dr. Abdrabbo Abdel-Azim Abdrabbo Shehata	Morocco	2021
2	Dr. Nasser Sedaghati	Iran	2020
3	Fuqiang Tian	China	2019

Sl. No.	Name of Winner(s)	Country	Year
4	MR. John Hornbuckle, Mr. Jamie Vleeshouwer and Ms. Janelle Montgomery	Australia	2018
6	Mr. Chris Norman and Mr. Carl Walters	Australia	2017
7	Prof. Li Jiusheng	China	2016
8	Prof. Li Xinjian	China	2015
9	Er. Jeff Shaw and Todd Kotey	USA	2014
10	Prof. Yi Yongqing	China	2013
11	Prof. Peng Shizhang	China	2012
12	Messrs Pieter S van Heerden and Charles T Crosby's	South Africa	2011
13	Dr. Keith Weatherhead, Mr. Melvyn Kay and Dr. Jerry Knox	UK	2010
14	Dr. Rai Niaz Ahmad	Pakistan	2009
15	Dr. Yella Reddy, Mr. Satyanarayana and Mr. G Andal	India	2008
16	Mr. Werner Arns and Mr. Herbert Arns	Brazil	2007
17	Prof. Kang Shaozhong	China	2006
18	Mr. Omar Redjepow	Turkmenistan	2004
19	Dr. Richard John Stirzaker	Australia	2003
20	Mr. Robert E. Merry	UK	2002
21	Prof. Tai Cheol Kim	Korea	2001
22	Prof. Mao Zhi	China	2000

(C) YOUNG PROFESSIONALS AWARD

Sl. No.	Name of Winner(s)	Country	
1	Dr. Alison Mccarthy	Australia	2021
2	Mr. Mohammad Sadegh Keshavarz and Dr. Hamed Ebrahimian	Iran	2020
3	Mohammad Bijankhan, Ali Mahdavi Mazdeh, Hadi Ramezani Etedali, Fatemeh Tayebi and Narges Mehri	Iran	2019
4	Mr. Amirali Fatahi & Ms. Fatemeh Sadat Mortazavizadeh	Iran	2018
5	Mr. Mahdi Sarai Tabrizi	Iran	2017
6	Dr Mohamed Elsayed Abdell Rahman Albaumy Elhagarey	Egypt	2016
7	Dr. Malcolm Gillies	Australia	2009
8	Dr. Amgad Elmahdi	Australia	2008
9	Ms. Neelam Patel	India	2006
10	Dr. Mohamed Maher Mohamed Ibrahim	Egypt	2005
11	Dr. Juan Antonio Rodriguez Diaz	Spain	2004
12	Mr. Tony L. Wahl	USA	2003
13	Dr. Ashutosh Upadhyaya	India	2002
14	Er. Sanjay M. Belsare	India	2001
15	Mr. Gao Zhanyi	China	1999

(D) FARMER(S) AWARD

Sl. No.	Name of Winner(s)	Country	Year
1	Mr. Gholamreza Ansari	Iran	2021
2	Mr. Mekala Siva Shankar Reddy	India	2020
3	Mr. Karan Jeet Singh Chatha	India	2019
4	Dr. Vijay Sharad Deshmukh	India	2017
5	Mr. Chandra Shekhar H. Bhadsavle, Mr. Changdev K. Nirguda and Mr. Anil D. Nivalkar	India	2016
6	Mr. Bhagwan M. Kapse	India	2015
7	Mr. Jerry Erstrom's	USA	2011
8	Mr. Arvind Narayanrao Nalkande	India	2009

MEMBERS WG-WATS (CURRENT)

ICID appreciates the following members of the Working Group – WATS for reviewing the manuscript of this publication and making valuable suggestions to improve it.

1.	Mr. Mehrzad Ehsani	Iran	Chair
2.	Mr. Adama SANGARE	Mali	Vice Chair
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18.	Dr. Mohamed H. Amer	Egypt	Member
19.	Eng. Rafat Nael AbdulGhani Al-Intaki	Iraq	Member
20.	Dr Joe Stevens	South Africa	Member

UNITS CONVERSION

Unit	Description	Approximate Conversion (if not standard)
acre		
BCM	Billion Cubic Meter	
cm	centimetre	
ds	Desi-siemens	
fed	feddan	Area (Egypt): After 1830, approximately 4,200.833 square meters (about 1.038 acres). Also romanised as faddan, and called feddan masri. When Egypt adopted the metric system, the feddan was the only old unit that remained legal. Currently taken as 0.42 hectares.
gal	gallon	
gm	gram	
ha	hectare	
h	hour	
hp	horsepower	
inch		
kg	kilogram	
kirat		Area (Egypt): 175 m^2
Kpa	kilo-pascal	
kW	kilo-watt	
kWh	kilo-watt-hour	
L	litre	
meska		Area (Egypt)
MCM	Million Cubic Meter	
mg	milligram	
Mha	Million Hectare	
mile		
ML	Megalitre or Million Litre	
mm	millimetre	
Mpa	Megapascal	
MT	Metric Tonne	
mu		Chinese unit of land measurement that varies with location but is commonly 806.65 square yards (0.165 acre, or 666.5 square metres).
Q	Quintal	100 kg (India)
RMB		Currency (China)
s	second	
T or Ton	Tonne	

Table of contents

1. INTRODUCTION

1.1 BACKGROUND

1.1.1 Water is Life

Human evolution has been a journey of multi-dimensional innovations over thousands of years. Water and other vital natural resources such as land, air, and minerals made it possible for humans to rapidly populate the earth using selective domestication of plants and animals in different geographies and climatic zones. During human evolution in various parts of the world, freshwater availability served as one of the primary factors for the emergence of human tribes, communities, and civilisations, influencing migration and invasion patterns to resource-rich lands offering better environmental conditions. Even at a biological level, among other chemical compounds, water has the highest concentration in living organic cells and is attributed to the emergence of life on earth. Considering the above, the common phrase "Water is Life" could not be an over-statement.

1.1.2 Water and Agriculture

Biological survival depends on availability and access to food which rain-fed agriculture provided for during the early evolutionary times. Natural precipitation contributes more to food production than constructed irrigation infrastructure worldwide. This dependence on rain or snowfall, significantly subjected to temporal-spatial constraints, was one of the major determinants of our nutritional choices. As civilisations progressed, humans started exerting greater control over natural resources, including water, to overcome these constraints. So, instead of settling near water bodies, we started diverting water from natural waterscapes towards human settlements to supplement our proximate water resources. Thus, giving birth to irrigation in 6000 BC in some parts of Egypt and Mesopotamia. A revolutionary innovation in itself, irrigation significantly transformed our capacities to farm, more extensive lands and with a diverse group of domesticated plants and animals for more nutritional and recreational food and fibre choices. Initially, our geographies determined most of our clothing and food choices, but irrigation diversified our approach and resources. Expanding civilisations created a new need for clean water for sanitation and domestic activities, strengthening the human-water relationship that flourished over the centuries in recorded history.

Agriculture became the primary livelihood, and it continues to be so in many developing and under-developed parts of the world. Over the years, subsistence farming transformed into intensive agriculture, which required a higher application of inputs to produce food, feed, fibre, and fuel. With the advent of multi-mode transportation through land, rivers, and sea, surplus production commodities were traded through the barter system or in exchange for valuable minerals such as gold, silver, and diamonds. Therefore, agriculture paved the way for economic development through regional and global trade.

1.1.3 Agricultural Development

Before the industrial revolution of the 17th and 18th Centuries, agriculture either dominated the manufacturing value-addition or supplied the raw material for most manufacturing processes for agricultural commodities such as cotton, silk, meat, and others. Consequently, agricultural development became the "development indicator" for communities, societies, kingdoms, nations, and other socio-political structures. As a trade ecosystem, agricultural inputs such as land, seed, fertiliser, pesticides, water, and labour also became economic commodities to maximise profits through the application of scientific knowledge and specialisation. Exponential development eventually led to a population explosion despite frequent wars and violent conflicts witnessed worldwide, which hampered production. Irrigation development played a paramount role in economic growth, which generated employment, livelihood avenues and drove industries to feed the growing population.

1.2 EMERGING GLOBAL ISSUES

1.2.1 Water Crisis

The World Water Development Reports (2009, 2012) observed how the concurrent global crises – climate change, energy, food security, economic recession, and financial turbulence – are interrelated and negatively impact water resources.

The Comprehensive Assessment of Water Management in Agriculture (CA, 2007) posed the question: "Is there enough land, water, and human capacity to produce food for a growing population over the next 50 years

– or will we 'run out' of water?" It further states that it is possible to produce food, but today's food production and environmental trends are expected to lead to crises in many parts of the world. If we act to improve water use in agriculture, we will meet humankind's acute freshwater challenges in the coming 50 years. To put it simply, business as usual is not an option. Radical changes are needed in the way water is governed and managed to tackle the impending crisis. Over the years, increasing population and scattered sectoral demands have made the situation more challenging.

1.2.2 Water Scarcity

Water is a finite and irreplaceable resource that is fundamental to human beings. It is only renewable if well managed. Today, more than 1.7 billion people live in river basins where depletion through use exceeds natural recharge, a trend that may see 2/3rd of the world's population living in water-stressed countries by 2025. Water can pose a serious challenge to sustainable development. Still, if managed efficiently and equitably, water can play a critical enabling role in strengthening the resilience of social, economic, and environmental systems in the light of rapid and unpredictable changes.

Demographic pressures, the rate of economic development, urbanisation, and pollution are all putting unprecedented pressure on a renewable but finite resource, particularly in semi-arid and arid regions. The world's population is expected to increase to over 9 billion by 2050, and whether urban or rural, this population will need food and fibre for its basic needs. It is estimated that agricultural production will need to expand by 70% by 2050. An additional billion tonnes of cereals and 200 million tonnes of meat will need to be produced annually to fulfil the growing food demand. There is sectoral competition for available freshwater resources between agriculture, industries, services, ecological, and household needs at the country level. In most cases, this reallocation for increased water requirements is expected to come from agriculture due to its high share of water use.

The projections for both water and food security appear to be contradictory. On the one hand, there is a need to use less water in agriculture. Still, on the other hand, more intensive use of water in agriculture is a crucial element of sustainable intensification of food production. Resolving this apparent quandary requires a thorough reconsideration of how water is managed in the agricultural sector and how it can be repositioned in the broader context of holistic water resource management and water security.

Of all sectors of the economy, agriculture is the most sensitive one to water scarcity. It is also the sector with the most significant scope or potential for making more water available for other sectors of the economy. Agriculture, mainly irrigated agriculture, is undergoing rapid changes and facing both old and new challenges. Farmers worldwide must adapt to a world where trade and globalisation have rapidly increased the interconnectedness and interdependence between production and consumption patterns. Technological advancements have boosted agricultural productivity. The green revolution and subsequent developments in agronomy have helped agricultural production outpace population growth and feed an ever-increasing number of people with even more diversified high-quality food choices.

1.2.3 Competing Water Demands

Agriculture is both a cause and a victim of water scarcity. Inter-sectoral competition for water is the most obvious in the hinterlands of large urban centres. Still, water scarcity can arise in all catchments where the intensification of agriculture in headwater areas reduces water supply downstream. Unsustainable groundwater use can have long-term impacts on agricultural production in regions such as South Asia, where a boom in groundwater-based irrigation in the 1980s and 1990s led to a boom in agricultural production constrained by aquifer depletion. The biggest challenge is that agricultural production will decline in highly populated areas when demand rises, and food security is coming to the fore in all regions.

A growing, increasingly prosperous, and rapidly urbanising global population will demand more food, energy, and water resources to meet its needs. These demands from industrial development and rapid population growth call for immediate water and sanitation infrastructure investments. Expected trends include:

(a) Increased Water Consumption: In the absence of any change in consumption patterns, by 2030, the shortfall between demand for and supply of water is projected to be 40%.

(b) Increased Food Demand and Changing Diets: Projections show that providing food supplies for a world population of about 9 billion people in 2050 would require an overall increase in the provision of "on-the-plate" food by some 70% by 2050. This demand can be met by reducing food (and water) wastage.

(c) Increased Demand for and Access to Energy: Almost all of the increase in energy demand will come from non-OECD countries as more people gain access to electricity. Indeed, forecasts suggest that world energy consumption may increase approximately 50% between 2010 and 2040.

(d) Climate Change Impacts: Climate change will compound pressure on resources and policies to adapt to and mitigate. Furthermore, these pressures will be unevenly distributed worldwide, with the most significant impacts occurring in populations and locations characterised by low resilience.

1.2.4 Key Challenges

Water is central to the world's development challenges. Water is the nexus, whether food security, nutrition security, poverty reduction, economic growth, energy production, or human health. Water is a critical factor in achieving Sustainable Development Goals. Without water security, there will be no food security, energy security will be compromised, and poverty reduction and economic growth will not be sustainable. Feeding the world's growing population and finding the land and water to grow the food continues to be a fundamental and sizeable challenge. It is an enormous task because the required increase in food production to meet future needs will be achieved with fewer land and water resources.

The steps and actions needed to achieve water security must be embedded into national development plans, such as poverty reduction strategies and comprehensive development frameworks. There is a need to bring together fragmented institutional responsibilities and interests in water, such as finance, planning, agriculture, energy, tourism, industry, education, and health. This means that we must demonstrate why water, and better water resources management, in particular, is vital for development. Simply drafting water resource management plans does not solve water problems.

Food Security

Agriculture uses more water than any other area of human activity. Food and water security are therefore inextricably linked. Without water security, there will be no food security. Producing enough food for one person for one day requires about 3,000 litres of water – or about 1 litre per calorie. When compared with the 2–5 litres needed for drinking, it is clear that water for food production is a critical issue as populations and wealth grow. In addition to this "hunger for land" and "thirst for water," global agriculture will have to cope with the burden of climate change, whose likely impacts have been documented in great detail in many reports. Most of them conclude that the global food production potential is expected to contract severely, yields of major crops like wheat and maise may fall globally, and prices for the most important crops – rice, wheat, maise, and soybeans – may rise. In addition, severe weather occurrences such as droughts and floods are likely to intensify and cause more crop and livestock losses. Increased water use efficiency and productivity in agriculture are driving factors in achieving water and food security. Concerted action to achieve more crop productivity from every drop of water used for agriculture is essential.

Climate Change

The rising awareness, though late, of the severe impacts of climate change on our planet has challenged our optimistic vision of continuing progress and the relevance of the current world economic model. We have not only come to realise that the earth's resources cannot, in the long run, meet the demand of a world population following the model of developed societies, but we have become, at the same time, conscious of the immense risks associated with the negative impacts of climate change on the sustainability of the world's natural resources. Climate change is a disrupter to achieving water security.

Floods and Droughts

Floods are the most common natural disaster and cause more deaths and damage than any other type. Yet floods also sustain aquatic life and riverine biodiversity, recharge aquifers, enrich soils, and provide an essential means of irrigation in some of the world's poorest areas. One of the most severe by-products of global warming and climate change is increasing and widespread drought, which will affect many nations in the future, especially those in regions already prone to experiencing such phenomena. Droughts significantly impact food security, especially for vulnerable populations, and significant long-term socio-economic impacts.

Urbanisation

Today, 50% of the world's population lives in urban areas and, with changing demographics characterized by massive migration into cities, by 2025, it is projected to be 60%. Urban water and wastewater management is a severe threat in most developing countries. It is essential to recognise wastewater as a new water source to fulfil demands efficiently.

Conflicts

For centuries, humankind has struggled to allocate the earth's water, and at times, competition for the resource has led to conflict. Today, population growth, surging demands for food and biofuels, improved living standards, rising demand for water, degradation of water resources, and changing weather patterns mean there is even less water to go around. The development will increase the risk of severe conflicts over water and negatively impact the already poor and vulnerable sects of the global population. Ensuring the availability of water is becoming an ever more difficult task.

1.2.5 Sustainable Agricultural Development

The challenge of agriculture today is sustainably producing adequate and nutritious food for a growing, sophisticated, and increasingly mobile global population while preserving and preferably enhancing the natural resource base. This challenge goes beyond the ability to produce more food. Agriculture is a significant employer, provider of livelihoods in multiple ways, and a buffer in population mobility. Changes in the broader landscape, including external drivers and dealing with these, have far-reaching implications. Today's challenge is more significant than ever because the drivers of change and water in agriculture have accelerated. Population growth, mobility, economic development, changing consumption patterns, diets, social changes, and technological developments are all exacerbated by climate change impacts. These drivers create largely negative pressures on agriculture and water resources and the other elements of the resource base while interacting among themselves, complicating the ways and means to deal with them appropriately.

Within this framework, the agriculture sector, from policy to practice, can be sustainable when the following five principles, developed by FAO in collaboration with the member state governments and partners, are adequately addressed (FAO, 2014):

(a) Improving efficiency in the use of resources is crucial to sustainable agriculture;
(b) Sustainability requires direct action to conserve, protect and enhance natural resources;
(c) Agriculture that fails to protect and improve rural livelihoods and social well-being is unsustainable;
(d) Enhanced resilience of people, communities, and ecosystems is key to sustainable agriculture; and
(e) Sustainable agriculture requires responsible and effective governance mechanisms.

Irrigation and Drainage (I&D) systems: Most governments and water users fail to invest adequately in maintaining irrigation and drainage (I&D) systems. While inadequate management and operation may play a part in the poor performance of I & D systems, it is mainly the failure to adequately maintain systems that results in their declining performance and the subsequent need for rehabilitation. The failure to provide adequate funds for maintenance of the I & D system has resulted in the all too familiar "build-neglect-rehabilitate-neglect" cycle.

Improving water use efficiency in agriculture also depends on matching off-farm improvements with incentives and technology transfer for on-farm investments in improved soil and water management and improved seeds. Advanced techniques such as enhanced seeds, low-till, alternate wetting and drying, sustainable rice intensification, and others exist but require matching improvements in water delivery systems to provide on-demand service using soil moisture sensors and satellite evapotranspiration measurements.

The following factors, either alone or in different combinations, have contributed or may continue to affect the availability of good-quality irrigation water in different regions of the world.

(a) Inherited shortage of water in certain areas as a result of their geographical location where rainfall is very low, groundwater use is not feasible due to economic, political, and/or technical reasons, water treatment options have economic limitations, and transportation of good-quality water from other areas is not feasible.
(b) Increased cropping intensities on already cultivated lands consume more water per unit area cultivated, i.e., vertical expansion of irrigated agriculture, which has simultaneously resulted in land degradation and associated water resources at some places.
(c) Cultivation of crops on new lands requiring an additional amount of water, i.e., horizontal expansion of irrigated agriculture, has deteriorated surface and groundwater quality at places where marginal lands were brought under cultivation without appropriate management practices.
(d) Increased industrial and domestic use of good-quality water due to an increase in population coupled with higher living standards. Most of the projected global population increases are expected to occur in third-world countries that already suffer from water, food, and health problems.
(e) Contamination of surface and groundwater resources by various point and non-point pollution sources.

Since freshwater has always been an integral component of food production, it is evident that the water requirements associated with producing food for the future world population are immense. It is, therefore, apparent that strategic water management will be the key to future agricultural and economic growth and social wealth, both in developed and developing countries.

Agricultural Productivity

Improving agricultural productivity while conserving and enhancing natural resources, such as water, is an essential requirement for farmers to increase global food supplies on a sustainable basis. The role of smallholder farmers and their families in increasing agricultural productivity sustainably will be crucial. Farmers are at the centre of change involving natural resources and need to be encouraged and guided, through appropriate incentives and governance practices, to conserve natural ecosystems and their biodiversity and minimise the harmful impact agriculture can have on the environment

Agriculture involves both rain-fed and irrigation farming. About 80% of globally cultivated land is done with rain-fed agriculture, accounting for 60% of world food production. Using innovative methods to enhance efficient and creative water use in rain-fed agriculture can increase production. The productivity of irrigated land is more than three times that of unirrigated land. Around 40% of the world's food is produced on 20% of irrigated land. Many of the methods known to conserve water and use it efficiently have been practised for thousands of years in some very arid regions of the world with great success. The best systems require little maintenance while yielding maximum results. Adding water during crucial growth periods can significantly increase crop yields.

Often a significant part of water drawn for irrigation doesn't reach crops due to leaks along the conveyance systems that transport water from the withdrawal point to the fields. Only part of the water reaching fields are used to grow crops, and the rest is lost due to evapotranspiration and infiltration in the soil. Different strategies exist to save water in agriculture, which, when integrated, can increase water-saving.

Water Productivity

The major challenge facing irrigated agriculture today is producing more food using less water per unit of output, i.e., increasing water productivity in irrigated and rainfed agriculture. This goal will only be achieved if the appropriate water-saving technologies, management tools, and policies are in place. All those involved in irrigation water management – managers, farmers, workers need to be encouraged and guided, through appropriate policies and incentives, to save water and minimise wastages to mitigate adverse environmental impacts.

Irrigated agriculture is often termed as the guzzler of water. Between 1950 and 2000, the world population increased threefold, irrigated area doubled, while water diversions to irrigated agriculture increased sixfold. Some major river basins approached an advanced level of water depletion. Water is already a limiting factor for agricultural production in arid and semi-arid countries. Climate change is likely to exacerbate the water scarcity situation further. Thus, under a business-as-usual scenario, there may not be enough water to produce the food needed to feed the world in 2050. Therefore, it is imperative to promote water-saving practices in irrigated agriculture on a large scale. Consequently, many international organisations, national governments, research institutes, farmers' organisations, and private agencies worldwide are focusing their efforts on developing and applying various water-saving measures.

Water-saving approaches/practices in irrigated agriculture may be categorised as engineering, agronomical, management, and institutional. A vast range of technologies is available for improved operation, management, and efficient irrigation water use, ranging from simple siphon tubes for field water application to sophisticated canal automation and telemetry. The success of these approaches depends on the level of their integration and socio-economic dimensions of a given locality.

1.2.6 Key Challenges in Some Selected Countries

AUSTRALIA

Australia is the driest inhabited continent. The late 19th and early 20th centuries saw a dramatic increase in irrigation development in the Murray Darling Basin and elsewhere as governments attempted to overcome natural water scarcity. Recognizing the need for additional water sources, the Australian government developed the water potential of eastern flowing rivers. This additional resource was created at the expense of lost agricultural production value, lost investment, and increased uncertainty about water availability.

Some of Australia's fundamental challenges are water accounting for equitable and transparent water governance, and engineering challenges include modernization and automation of irrigation infrastructure for water-saving in agriculture. The water saved has been reallocated for ecological water needs towards sustainable development. Other challenges include Public-Private partnerships and the adoption of water trading practices.

CHINA

As a significant part of China's irrigation management, rural water cooperation organisations are an innovation that suits rural land contract reform and an essential form of self-governance by the grassroots in the rural area. In China, irrigation and drainage facilities are jointly managed by professionals and the general public. For large and medium-sized irrigation and drainage projects, the government set up specialised regulatory bodies staffed with professionals in the irrigation and drainage sector. For on-farm projects and small irrigation and drainage facilities, the format of self-construction and self-management by farmers is promoted.

Surface irrigation is the dominant irrigation method in China, which means relatively low water use efficiency. The rural water cooperation organisations are responsible for pricing the irrigation water, ensuring water-saving and reduced water use per unit area hence increasing irrigation efficiency. However, to improve irrigation water management, rural water cooperation organisations as the governing body should focus on advancing the monitoring and supervising mechanisms of water consumption. Currently, the Chinese government is investing heavily in the renovation and construction of irrigation and drainage facilities, improving the irrigation and drainage system and increasing auxiliary projects. While accelerating project construction, the government is also promoting the construction of water measuring facilities to control the total volume of irrigation water consumption and setting up water use quotas, carrying out scientific irrigation with the results of irrigation tests, formulating rules and regulations on water rights and water rights trade, enhancing irrigation water management, and facilitating water-saving in agriculture.

INDIA

In a monsoon-dependent farming system with unreliable and scanty rainfall over large areas, irrigation has been crucial for the growth of agricultural production in India. However, irrigation development has not seen the desired and viable coverage due to various socio-economic causes at both macro and micro levels. The issues encountered can be broadly classified under two streams:

(a) Inadequacy of irrigation potential created (IPC) concerning the ultimate irrigation potential (UIP) available as per techno-economic assessments.

(b) Broad gap between irrigation potential utilised (IPU) and the created potential.

India's demand and supply imbalance challenge can be managed by enhancing supply (i.e., supply-side solution) and curtailing demand (i.e., demand-side solution).

The first set of requisite interventions pertains to the category of structural advancements, mostly of engineering nature, which will require immense financial resources and capacity building of the government's irrigation-related institutional framework. The second set pertains to the category of non-structural interventions, seeking behavioural changes in farmers' irrigation practices, which will require deeper penetration of water education and awareness, higher level of collaboration with non-governmental organisations and other institutions, as well as capacity building of the Water Users Associations (WUAs).

Whereas the first option needs a significant amount of physical and technological resources, the demand side solutions need enormous social mobilisation, drastic changes in economic and marketing models, and individual choices. Mobilizing one with the exclusion of the other may create undesirable effects, and therefore, a balance must be sought between the two. There lie the policy and development challenges of the water sector.

INDONESIA

As an archipelago, the conditions and problems of water resources in Indonesia vary enormously between Java, Bali, and other islands. Because of the tropical climate condition, the national gross per capita water availability is very high. But the monsoon characteristics and urbanization coupled with economic development have created conflicts in the distribution and utilization of these water resources, both at the surface and groundwater. Therefore, putting water security at risk in the coming future, especially in the most populated islands of Java and Bali.

Issues related to Land and Water

(a) Fragmented Government's Institutional Set-Up

(b) Degradation of Catchment Areas

(c) Limitedness of irrigated land area

(d) Damage of Existing Irrigation schemes

(e) Agricultural land conversions

(f) Increasing Demand for Non-Agricultural Water

(g) The limited scope of irrigation budget allocation from regional governments

Other challenges include water allocation and service delivery and water for agriculture and irrigation. The engineering challenges include:

(a) Storage Dams: In Indonesia, less than 10% of the irrigation area has secured water supply from a storage dam, with the rest 90% dependent on the 'run-of-the-river weirs, but with global warming and deforestation of the catchment, this is not a sustained situation.
(b) Geo-spatial Approach: To support food security, agricultural production, especially rice production, can be enhanced by rehabilitating deteriorated irrigation schemes and reservoirs and ensuring that the required Operations and Maintenance (O&M) is conducted on all schemes. In this respect, special emphasis and support need to be given to Kabupaten or Kota and selected provincial government departments to raise awareness and increase the available water capacity.
(c) Low land Development: As the vast majority of Indonesia's rice-producing area is on Java while Java is also the centre of national industrial development, the irrigated land on Java Island is reduced by around 50,000 ha/year.

IRAN

The climatic conditions are arid and semi-arid, and about 2/3rd of the country receives less than 250 mm of precipitation per year. It means that optimized use of water resources is essential in this country. Out of 37 Mha of potential area for agriculture, about 8 Mha are under irrigation. In the past two decades, the limited budget for construction, the conflicts between social perceptions, and the inadequately designed irrigation schemes have been the main constraints in these projects. The past decades witnessed the migration of the rural population to the capital, and urbanization has increased the domestic water demand, putting enormous pressure on the agriculture sector to reduce its water consumption.

Some of the recent irrigation management reforms in Iran are:

(a) Privatization of modern Irrigation systems operations
(b) Supportive laws and intensive policies for optimized use of agricultural water
(c) Supportive laws for Financial Support (National and International)

JAPAN

In its long history of more than 2,000 years, agricultural water usage (irrigation and drainage systems) in Japan has been consistently protected and grown by the efforts of farmers and other stakeholders in agriculture in each era. The multi-dimensional functions of irrigation and drainage systems are not limited to their contribution to the long-term food security realized by ensuring irrigation water, which is indispensable for a stable food supply. The water from rice-growing fields and other fields has been used to stabilize the river flow and recharge the groundwater, thus playing an essential role in maintaining a healthy circulation of the drainage basin.

Improvement of water usage efficiency: While the development of agricultural irrigation and drainage facilities enabled the mechanization of rice paddy farming and independent irrigation and drainage systems for each parcel of land, new challenges like part-time farming and the ageing of farmers have emerged. Specifically, measures are needed against the concentration of water consumption at peak times, automatization, improvement in land management practices, and energy-saving measures for agricultural irrigation and drainage facilities. In densely populated water basins, where the facilities significantly impact the water supply to fulfil demands unique to urban areas in drought, land improvement districts (LIDs) should cooperate with the local governments to coordinate water usage in the basin.

SOUTH KOREA

South Korea is in a monsoon area, and the wet and dry seasons repeat every year with seasonal variation of precipitation requiring irrigation and drainage systems for regular agricultural activities. Usually, June-August is the wet season. While most of the yearly rainfall occurs during this period, the other nine months receive 30% of the annual rainfall. Most crops are cultivated from March to October, except for protected farming and winter crops.

Issues and challenges related to land and water in South Korea are:

(a) Fortunately, large-scale projects for integrated agricultural development resulted in 100% of rice self-sufficiency by overcoming the population growth.

(b) The government's agricultural policy has shifted to 'rural community' development from agricultural infrastructure development since 1990 for farmers' protection from the coming General Agreement on Tariffs and Trade GATT-UR and Free Trade Agreement (FTA) rural life quality improvement.

(c) The environmental problem has become a social issue since 1990. The compensation for fishery rights by tideland reclamation the value comparison between mudflat ecological system and agricultural land development impeded and retarded the project progress for a long time. In addition, the non-point source pollution from agricultural lands and point source pollution from rural communities are still critical issues to prevent the water quality decline by increasing investment in BMP and village-unit sewage treatment facilities.

(d) Climate change approached agriculture as a significant threatening factor. The Information and communication technologies (ICT) application to Irrigation and Drainage (I&D) facilities has been the solution for future climate change adaptation and mitigation.

NEPAL

Out of 2.7 Mha of agricultural land in Nepal, only 1.4 Mha have irrigation facilities. The majority of irrigation systems are small and medium scale, including groundwater irrigation. Agriculture is a mainstay of the economy of Nepal, providing about 33% of the gross domestic product (GDP) and supporting the livelihoods of most of the population. Livelihoods based on agriculture are vulnerable due to the vagaries of the monsoon, climate, and topography.

Irrigation development and management are undertaken by different government and private sector agencies in Nepal. The National Water Plan (NWP) 2005 puts physical targets in the irrigation sector for increased agriculture production. These targets are for round-the-year irrigation, improved irrigation efficiency, increased cropping intensity, and more irrigation facilities in the potential irrigable area.

Challenges in Nepal include the lack of capacity/resources (technological, financial, human, and institutional) of the WUAs, lower technological uptake, older infrastructure requiring rejuvenation, insufficient water information or accounting, lack of water-pricing mechanisms, unavailability of knowledge and skilled professionals in some countries, absence of private sector participation, and difficulty in upscaling the WUAs. The legal and institutional framework issues affect the performance of WUAs to a large extent. Thus, for smoother functioning of WUAs to manage water efficiently, apart from technical issues, other issues such as social, political, economic, environmental, and human aspects of Water Resources Management (WRM) also need to be considered carefully.

UKRAINE

As a result of climate change, the area under dry and very dry zone has increased by 7% and covers more than 29.5% of the territory or 11.6 Mha (37%) of arable land. The area with excessive and sufficient atmospheric moisture, on the contrary, decreased by 10% and occupied only 22.5% or 7.6 Mha of arable land. Thus, permanent irrigation in Ukraine requires 18.7 Mha of arable land, 4.8 Mha - periodic.

The existing state policy in the water management area is ineffective because of the unresolved and unsettled nature of several issues, namely: the absence of a single independent authorized body that would be responsible for the development, monitoring, and implementation of state water policy; the lack of a delimitation of the functions of water resources management and provision of water services to all consumers; uncertainty of the status and authority of the basin councils; unregulated participation of water consumers at all levels of water resources management and land reclamation, etc.

To meet the existing challenges and implement the country's existing potential in the field of irrigation and drainage, a strategy was developed for the restoration and development of irrigation and drainage systems in Ukraine by 2030 involving experts from World Bank in this project. Reforms are necessary for a new market economy and to increase the efficiency of the irrigation and drainage sector.

1.2.7 Tackling Water Scarcity in Agriculture

Water is essential for agricultural production and food security. The water of appropriate quality and quantity is critical for drinking and sanitary purposes and food production (fisheries, crops, and livestock), processing, and preparation. Nevertheless, significant parts of the world are struggling with water scarcity. The excessive use and degradation of water resources threaten the sustainability of livelihoods dependent on water and agriculture. Achieving the required production levels from an already seriously depleted natural resource base requires profound changes in our food and agriculture systems, ensuring global food security, providing economic and social opportunities, and protecting the ecosystem services on which agriculture depends.

The world is rapidly becoming wealthier and more urbanized, and food preferences are changing to reflect this: the consumption of staple carbohydrates is on a declining trend while demand for high-value products such as milk, meat, fruits, and vegetables – which, in many parts of the world, have much higher water footprints – is increasing. At the same time, competition for increasingly scarce land, water, and energy resources is intensifying, further aggravated by the existential threat of climate change. Climate change will significantly impact agriculture by increasing water demand, limiting crop productivity, and reducing water availability in areas where irrigation is most needed or has a comparative advantage. Reduced river base flows, increased flooding, and rising sea levels are predicted to affect highly productive irrigated systems dependent on glacier melt (e.g., in the Punjab region (India), and Colorado (United States)) and lowland deltas (e.g., those of the Indus, Nile, and Brahmaputra–the Ganges–Meghna rivers). In the semi-arid tropics, droughts and floods are expected to increase in frequency and severity. Climate change is likely to significantly affect the rural poor by reducing crop and livestock yields.

Addressing water scarcity in the agriculture sector directly contributes to the 2030 Agenda for Sustainable Development and its SDGs and the Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC).

Some key questions to be addressed

(a) What can agriculture do to address water scarcity in climate change while ensuring food and nutrition security?

(b) What responses can the agriculture and food sectors offer to alleviate the impacts – and reduce the risks – of water scarcity?

(c) Agriculture holds the key to tackling water scarcity in a changing climate. Agriculture is not only the largest water user globally; it is also a significant source of water pollution. Therefore, the sector will be crucial in addressing water scarcity in the context of climate change.

(d) Adaptation: Agriculture must adapt to the impacts of climate change and improve the resilience of food production systems to feed a growing population with less water.

(e) Effective governance and management: Innovative and effective governance mechanisms and investments in water technologies and infrastructure are needed to address growing water shortages and to ensure that water is allocated in ways that ensure its efficient use, protect the natural resource base, and secure access to water for household use and agricultural production.

(f) Improving agricultural water productivity sustainably: Agricultural productivity should not only be looked at in terms of land but in terms of water productivity, maximizing the return on water from a diverse range of activities. Crop water productivity can be improved by increasing yields (production per unit of land) through good agricultural practices based on soil and water management (e.g., precision irrigation), fertility and pest control, and improved genetic materials, considering the environmental impacts this may have. Crop water productivity can also be improved through deficit irrigation – that is, by applying water to crops in only the most drought-sensitive periods and avoiding irrigation in other periods.

(g) Improving and climate-proofing irrigation services ("soft" measures) and infrastructure ("hard" measures): Shifting towards more service-oriented and participatory approaches can improve access to and the management and maintenance of infrastructure and thereby increase water-use efficiency.

(h) Wastewater management: Using alternative sources of water while ensuring food safety. This refers to the reuse of treated wastewater for food and non-food production. Food safety standards and guidelines are needed to ensure that crop, agroforestry, and fish production using wastewater streams meet human health standards.

1.2.8 Conclusion

Freshwater governance holds a prominent position in the global policy agenda. Due to population growth and rising incomes, burgeoning water demand combined with supply-side pressures, such as environmental pollution and climate change, create acute global water scarcity conditions. This is a significant concern because water is a primary input for agriculture, manufacturing, environmental health, human health, energy production, and every economic sector and ecosystem.

The prospects for agriculture to respond to the increasing food demand by 2050 are supported historically but if and how this is to be accomplished is yet to be established given the state of the associated resources, investment policies, and equity issues surrounding them. And this could only be achieved by preserving the ecosystems whose services are essential for all life on earth.

It is a well-known fact that water scarcity is a significant constraint for agricultural development across all geographies, especially in arid and semi-arid countries. Sustainable agricultural development is impossible without renewable water supplies and appropriate and reliable water control and management. More than ever, it is required today to utilize water while storing it wherever possible efficiently. Promoting innovations along with continuous monitoring mechanisms is the requisite approach.

Water conservation in the farming business has become an essential component of the production cycle. While it's not at the top of the priority lists for the farmers' community, given their water requirement for livestock and crop production, it's still imperative to implement water-saving strategies in their day-day practices. There aren't always water-efficient equipment options in agriculture, but it's more about the technique one uses with the equipment that can save water for a given crop per unit area. It is possible to use drone technology and artificial intelligence (AI) software to monitor farmlands and generate real-time reports of where and how much water is being used.

Water-saving challenges in developing countries include poor infrastructure, need for rehabilitation of old systems, low irrigation efficiencies, negligible reuse and use of poor quality water for irrigation, and traditional/conventional irrigation methods. Challenges in developed countries include water quality management, environmental sustainability, use of high-tech irrigation systems valuing water, integrated and holistic approach towards water management, and public awareness in water-saving.

ICID instituted the 'WatSave Awards' in 1997 to promote and recognize such initiatives, innovations, and management practices that led to water conservation or water-saving in agriculture, which can further be replicated in other parts of the world. The aim is to disseminate the knowledge generated through the awards widely for field adoption in new areas and appreciated by irrigation communities worldwide. The motivation is to address the global challenges and contribute towards meeting the Sustainable Development Goals.

2. WATSAVE AWARDS

2.1 BACKGROUND

As a follow up to the 15th ICID Congress in Netherlands in 1993, a WatSave Work Team was formed, which mooted a proposal in 1997 to institute WatSave Awards with the objective of promoting and recognizing water conservation success amongst member countries. The proposal was approved in principle by PCTA as well as IEC and ICID instituted WatSave Awards in the year 1997. The Work Team prepared the conditions and criteria for the Awards and presented these to the Management Board for approval. These were subsequently revised in 2007 and 2010 by IEC. The WatSave Scheme is presented herein to consolidate all the decisions taken by the IEC based on the recommendations of WG-WATS, Jury Members, and PCTA from time to time. It also includes some of the recommendations made, but not followed up or approved subsequently by IECs of that year, which needs special consideration.

2.2 SCOPE AND OBJECTIVE

The award(s) is/are presented to an individual or a team for an innovation that contributes to water conservation / Water-Saving for increasing the beneficial and/or efficient use of water to develop and improve the sustainable use of the critical resource.

2.3 SCOPE

The primary emphasis of WatSave Award is on the achievement itself. It is “an award for the achievement to the individual or team behind the achievement” in that order. The purpose and spirit behind ICID WatSave awards are as follows:

(a) The awards are intended to relate to activities or related sets of activities and not to highlight the overall professional accomplishments of an individual or any group.

(b) The awards are not intended to acknowledge research studies, per se, but rather to recognize accomplishments in saving water.

(c) Savings can be on a pilot scale or over a larger area, but they must have been introduced in the field to farmers or managers and applied by them, rather than remaining purely hypothetical.

The WatSave Awards are given in four categories as under.

2.3.1 WatSave Technology Award

This award is given for work promoting and encouraging the best technological applications or projects which have been successful in saving water and/or recovering waste waters/low quality waters.

2.3.2 WatSave Innovative Water Management Award

This award is given for innovation promoting non-technological interventions and/or innovative land and water management/techniques for increasing the availability of water for different uses; Promoting research that leads to substantial savings in water applications or uses; or Promoting development of new policies/approaches for Water-Saving leading to cost effective and beneficial use of water.

2.3.3 Watsave Young Professional Award

This award is given for water saving/ conservation work by young professionals (less than 40 years).

2.3.4 WatSave Farmers’ Award

This award is given to farmers for proven Water-Saving success story to promote successful water conservation.

2.4 THE AWARD

Each of the awards consists of an honorarium of US$ 2000 and a Citation. In the event of the award being made to a team, the amount shall be made to the nominated leader of the team that will be shared equally by all contributors. The Citation Plaque should bear the name of ICID as the promoter.

2.4.1 Dissemination of the Awarded Works

Based on the awarded works, ICID compiles and disseminates information on water saving/ conservation practices adopted by member countries world over through publications, website and organizing regional workshops. The developers of the innovation in terms of technology or management techniques will have to give an undertaking that they would provide full intellectual support to the Central Office in disseminating the achievement.

2.4.2 Procedure

2.4.2.1 Application

Nominations must comply with these rules:

(a) Nominations for the Awards are open to all professionals/ teams from ICID member countries/associate member countries as well as non-member countries, but the nomination must be made and validated by a member National Committee/ Committee/ Direct Institutional Member of ICID.

(b) A completed Nomination Form

(c) A type-written discussion of about 1500 words in English or French summarizing nominee's work related to water saving/conservation.

(d) A brief curriculum vitae (CV) of the nominee(s)

(e) Recent photograph(s) of the nominee(s).

(f) Entries should be sent electronically to the Secretary General, ICID to reach Central Office, New Delhi, by the Last Date of Receipt of Nominations at ICID Central Office announced by the Secretary General.

The idea of routing the nominations through the NC is to receive only one nomination per category per country after an initial scanning of the nominations for a sequential ordering based on merit and recommending only one. ICID member country can support one nomination from a non-member country, but every country should present only one candidate per category.

National Committee can nominate newly developed work of previous WatSave Award winners provided it is for a different innovation, as the purpose of the award is to identify successful Water-Saving technologies and management techniques in practice among the ICID family and disseminate them across the world. A nominated innovation once rejected for the WatSave award by ICID should not be re-nominated, even under a different category.

Please note that any nomination papers, as listed in above, if received after the Last Date will not be considered and forwarded to the Panel of Judges. All the papers related to nomination received on or before the due date will be acknowledged within a week by the Central Office by e-mail/fax. In case of non-receipt of the acknowledgement, the concerned National Committee/ Committee should contact the Central Office immediately.

2.4.2.2 ***Jury***

The nominations should be reviewed by a panel of 5 judges -- one each from the four regions of ICID (The Americas, Africa, Asia -Oceania and Europe) and fifth from any region but there shall not be two judges from the same country. The Chair of PoJ shall submit his report to the President of ICID giving reasons for selecting innovation for the award along with suggestions for improvement in the Scheme and its implementation or the way to disseminate it. A judge shall not evaluate a nomination from his or her own country. The panel will be appointed by President, ICID in consultation with the Chairman of the Working Group on Water-Saving for Agriculture (WGWATS).

The decision of the President ICID as arrived at through the process described herein will be final and binding. No discussion or correspondence relating to the award will be entered into.

2.4.2.3 The time schedule

Following time schedule for receipt of applications and announcement of the WatSave Awards will be adhered to as far as possible:

▪ Last date for receipt of nominations	120 days prior to the IEC date
▪ Review by the Panel of Judges	Within 60 days from the Last Date
▪ Declaration/Announcement of the Award	45 days prior to IEC date.

2.4.2.4 Evaluation Criterion

Technology and Management Awards

(a) Has the innovation made an outstanding contribution to water conservation and increased the beneficial use of water and/or freed water for other uses?

(b) Have the quantities of water saved been quantified and documented in the submission?

(c) Is there a reasonable expectation that the innovation will be sustainably practiced?

(d) Has the input and responsibility of each involved individual been delineated in the submission?

Young Professional Award

(a) Does the innovation promise to make an outstanding contribution to water conservation and increased the beneficial use of water and/or freed water for other uses?

(b) Has the innovation been pilot tested in the field and the potential water savings estimated and documented in the submission?

(c) Is there a reasonable expectation that the innovation can be sustainably practiced?

(d) Has the input and responsibility of each involved individual been delineated in the submission?

Farmer Award

(a) Is the innovation easily adoptable by other farmers in the region?

(b) Has the innovation made an outstanding contribution to water conservation and increased the beneficial use of water and/or freed water for other uses?

(c) Is there a reasonable expectation that the innovation will be sustainably practiced?

The Jury is empowered to shift a nomination from the category under which it is submitted to another category if such a shift is appropriate and beneficial and essentially warranted.

2.4.2.5 Authentication by the National Committee

For the Jury to adjudicate the awards, which are highly dependent on the actual application of the technology in the field, the nominating National Committee/Committee has to play a crucial role since members of the Jury will often not have detailed first-hand knowledge of the situation in a particular country, and thus would not be in a position to judge the realism of individual submissions.

National Committees should establish a broad based WatSave Awards National Screening Committee for screening the nominations at the national level against criteria laid down for each category of Award for which the nominations are proposed to be submitted to the Central Office and ascertain its eligibility. The Screening Committee should authenticate the innovation and its implementation and ensure that it is an original work carried out by the authors.

2.4.2.6 Financial

The host National Committee of IEC meeting of each year shall sponsor the Awards presented for that year. Central Office shall make adequate provisions in the annual budget as appropriate to disseminate the works awarded.

2.4.2.7 Contact

The ICID Central Office may be contacted for further information on the WatSave Awards.

2.5 WATSAVE GOALS

The WatSave awards aim at:

(a) Promoting and encouraging the best technological applications or projects which have been successful in saving and/or recovering waste waters/low quality waters.

(b) Promoting other non-technological interventions and/or innovative land and water management/ techniques for increasing the availability of water for different uses.

(c) Promoting research that leads to substantial savings in water applications or uses.

(d) Promoting development of new policies/approaches for Water-Saving leading to cost effective and beneficial use of water.

Each year ICID announces the WatSave Awards inviting nominations from the national committees and their national networks of scientists, engineers, young researchers, and farming communities.

2.6 PREVIOUS PUBLICATION

In 1995, a booklet providing preliminary information about the water-saving practices some of the ICID member countries adopted was published. Subsequently, a comprehensive document, "THE WATSAVE SCENARIO," comprising information received from 27 countries, was published in 1997. The document was very well received not only by ICID member countries but also by the international irrigation fraternity at large.

A book publication titled "Water-saving in Agriculture" was brought out by ICID in 2008. This book provided generic information on successful water-saving case studies from Australia, Brazil, China, India, Egypt, Korea, Pakistan, South Africa, Spain, Turkmenistan, and the USA. It also highlighted that water-saving efforts are more conspicuous in countries having significant irrigated agriculture. The innovative ideas and practices captured in this publication of 2008 were also aimed to enthuse other countries and ICID's mission to spread 'best practices' showcased in the book.

The book argued that there could perhaps be no single global solution or a blueprint for future challenges in agricultural water management. In the innovations presented in the 2008 edition, an attempt was made to highlight the scope offered by some of the technologies and management practices concerning broader aspects of water management. Some of the water-saving technologies were also briefed. It was indicated that some of these technologies will help double food production by 2030. Considering that the upscaling to achieve larger water-saving will depend on many factors, the complexity of addressing all the water management issues has been acknowledged; as was the case in the studies at basin levels undertaken by ICID while proposing policy support at the country level under CPSP (ICID, 2005). The use of surface and groundwater and their interaction in a basin, the need to integrate land and water uses for sustainable beneficial uses, the dimensions posed in respect of water quality when one considers the demands of water (water for people, food, and environment) require a good understanding of possible approaches and their implications.

2.7 CURRENT PUBLICATION

Summarizing the innovative nominations of newer technologies and management practices since 2009, this publication demonstrates the outcome of the initiatives of ICID members towards encouraging interventions for water-saving in agriculture. Successful technologies and management practices, developed by individuals, institutions, NGO's, farmers, and the stakeholder community at large, which resulted in water-saving from across the world, are presented in a briefcase-study form. The global issues and challenges in the water sector and international perspectives on water savings in different geographies have also been discussed.

While bringing out the contributions made toward water-saving techniques and technologies, efforts have been made to analyze these contributions concerning contemporary issues such as climate change, agronomic practices, agroecology, and the environment. The activities conducted towards the fulfilment of ICID's vision and contributing towards Sustainable Development Goals have been briefly analyzed while providing technical details of the nominations received by ICID for deciding upon the WATSAVE awards through a panel of judges comprising of global water experts.

3 WATER-SAVING TECHNOLOGIES

INTRODUCTION

Technological innovations are essentially the efforts of humankind to expand its physical and intellectual capacities to improve the quality of our lives. There are countless examples of our dependence on the technologies we see around us. Water is a finite resource requiring a continuous supply of innovations that maximizes food production in a situation characterized by a rapidly expanding and urbanizing human population faced with adverse climate change impacts. Water and food security are intertwined, and there is no other way around it but to increase water productivity in agriculture. Any amount of water saved directly enhances our food security.

This section presents a wide range of technological interventions for water-saving in agriculture nominated by ICID national committees working with their respective national human resources engaged in agricultural water sector research. As we glance through various nominations since 2009, we note that micro-irrigation through drips or sprinklers and their combination with other agronomic techniques have attracted many researchers. Another area of interest in the research communities is precision irrigation based on the accurate measurement of crop water demand at a given time and place. In this regard, information technologies also play a vital role in water-demand calculations and water-delivery mechanisms. Some nominations have also focused on improved traditional cropping and field preparation practices.

Since 2008 all the nominated technologies by various ICID national committees are briefly described in terms of their context, the area covered or water savings, adoption challenges (if any), and the way forward in this chapter.

3.1 AUSTRALIA

3.1.1 IrriSAT, Weather-Based Irrigation Management and Benchmarking Technology App

Submitted By: Mr. John Hornbuckle, Mr. Jamie Vleeshouwer and Ms. Janelle ***Montgomery (2018)***

A proper irrigation scheduling method adjusted to the actual crop water requirements is crucial to use available water resources better. Following this approach, an app called IrriSAT was developed in Australia to manage daily crop water use based on weather data.

IrriSAT is weather-based irrigation management and benchmarking technology app that uses remote sensing to provide site-specific crop water management information across large spatial scales at an acceptable resolution. It calculates crop coefficients (KC) from relationships with freely available satellite-derived Normalized Difference Vegetation Index (NDVI) data. Daily crop water use (ET_c) is determined by multiplying KC and daily reference evapotranspiration (ET_o) observations from nearby weather stations or nationally provided gridded ET_o data.

IrriSAT is moving weather-based scheduling into the future. It automates satellite processing from the Landsat NASA satellite platforms and the Sentinel ESA satellite platforms. Developed using the Google Earth Engine, it deliveries crop water use information to assist in irrigation scheduling and crop productivity benchmarking. It provides daily crop water use and a 7-day crop water use forecast. The app provides users with an estimate of crop water information that can assist with irrigation scheduling, ordering water, and benchmarking the performance of crops within and between fields and regions. Daily, it shows historical and current crop water use for a selected field or region as well as cumulative crop water from the planting date.

Users can also enter applied irrigations, and the tool undertakes a water balance for the selected field or region, showing irrigation deficit information. IrriSAT also undertakes a 7-day crop water use forecast and provides an estimate of the following irrigation period based on the user-selected irrigation deficit.

IrriSAT was introduced to irrigators through various mediums, including direct meetings and presentations to irrigators and irrigation consultants at farmer field events, throughout the Australian cotton and grain growing areas. The users reported water savings from using the tool in many ways, some of which are listed below:

(a) Modifying irrigation timing to better match crop water demands

(b) Better prediction of extreme climate events (like high ET_C days) and modifying irrigation schedules/deficits to minimize impacts on crops

(c) Identifying poorer performing areas within irrigated crops and changing management, for instance, using laser levelling

(d) Benchmarking performance of irrigated fields across farms and regions and using limited water resources on better performing fields

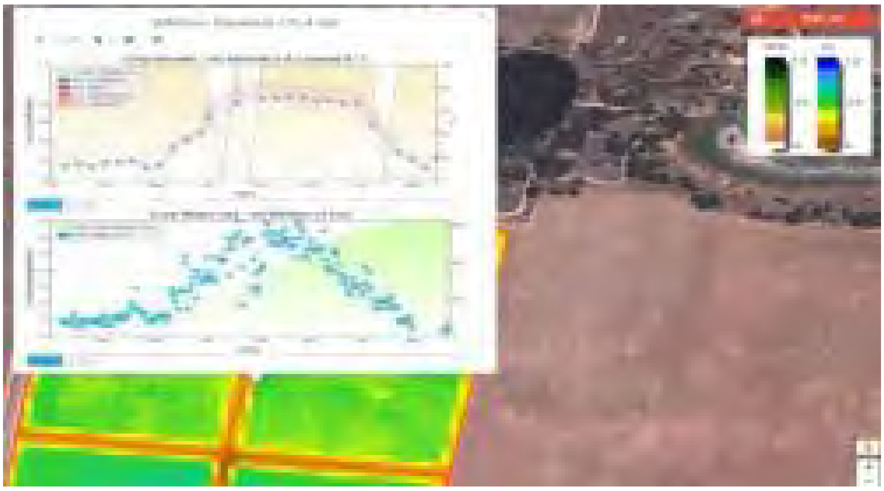

Figure 3.1 Daily crop water use information displayed in IrriSAT. Satellite and ET_O data are automatically ingested into the system as new satellite images and data become available.

Figure 3.2 Cumulative increase in IrriSAT users since the technology was introduced and major events associated

Currently, the app has full functionality across the entire Australian Continent and the USA. It allows users in these areas to historically get site-specific crop water use information. The app is useful across the globe to get seven-day crop water use forecasts. However, this scientific innovation needs the experience of irrigation scheduling and also access to and availability of gridded ET0 data.

3.1.2 'Water-Savings Calculator' for Estimating Water-Savings

Submitted by: Mr. Chris Norman and Mr. Carl Walters (2017)

In 2009, the Goulburn Broken Catchment Management Authority (GB CMA) and other Victorian and regional groups formed a consortium to develop the Farm Water Program (FWP). Developed under FWP, the water-saving calculator built on 20 years of agricultural data (Goulburn Murray Irrigation District (GMID), is an innovative way of determining water savings in real-time.

The water-savings calculator was first used in 2010 to determine water savings for the first few FWP projects. This followed further improvements and some work with FWP consortium partners to ensure that the calculations were correct and accepted. Several irrigators and irrigation specialists reviewed some examples of water-savings calculations and provided feedback on their accuracy and use.

Essentially the water-savings calculator gives an irrigator the confidence to adopt a new, more water-efficient irrigation technology by estimating the expected annual water savings if that irrigation technology were to be adopted on a predetermined land area. It does this by considering both the existing and future irrigation methods, the soil type, and the crop type. Eligible irrigators work with FWP staff to develop a project using a previously prepared property farm plan that details the proposed changes to the farm irrigation system. Irrigators can nominate all or parts of their property to be improved through an FWP project with a detailed change plan using the whole farm plan. The upgrades to the public delivery system included the renovation of sections of channels to minimize leakage and seepage using clay or plastic lining and installing remote-controlled, automated channel regulators and delivery gates to properties. Some sections of channels were replaced with pipelines, while others were removed where no longer required. These changes resulted in a higher level of delivery service for irrigation farmers with more consistent and larger flows of water available, which allowed for higher speed irrigations and improved water use efficiency. Irrigators were able to utilize the internet to plan and order the delivery of water onto their properties to suit their needs

FWP projects contain technologies and work for three types of irrigation systems listed below along with their activities:

1. *Surface irrigation*

   (a) Laser grading of irrigation bays to achieve a consistent grade down the bay to minimize waterlogging.
   (b) Drainage reuse systems for collecting irrigation and rainfall runoff and store it in a constructed sump and pump the water for irrigation.
   (c) Improved gravity earthen channels and pumped pipe and riser systems that can accurately control water flow.

2. *Micro and drip irrigation*

Installation and upgrades of pumps, piping, sprays, and drippers.

3. *Overhead sprinkler irrigation:*

Installation and upgrades of centre pivot, lateral move, and fixed sprinkler systems.

Water-savings Calculator: The water-savings calculator uses three crop types comprising

(a) Annual crops and pastures (ET_O = 3 ML/ha/year)
(b) Summer crops and horticulture (ET_O = 6 ML/ha/year)
(c) Perennial pastures, citrus, and almonds (ET_O = 8 ML/ha/year)

To calculate the amount of water saved, three groupings of soil types were used with the lightest textured soils, the sands, and sandy loams grouped as Light Soils, the loam soil types were grouped as Medium Soils and the clays grouped as Heavy Soils.

In a typical example with crops requiring 3 ML/ha/year, water-saving was as follows

(a) Improved surface irrigation adopting laser grading (14 ML/ha/year)
(b) Drainage reuse (16 ML/ha/year),
(c) Gravity earthen channel (36.5 ML/ha/year)
(d) Sprinkler upgrade, micro/ drip irrigation upgrade (no water-saving)

The water-savings calculator has now been used across 622 FWP projects, covering more than 37,000 ha with an expected 82,000 ML of the saved water. The improved irrigation systems provided irrigators with additional benefits of reduced labour requirement and ease of operating a more flexible irrigation system. Other irrigators have kept identical crops with the new upgraded system and experienced both a reduction in water use (ML/ha) and an increase in production (ton/ha and ton/ML).

The water-saving calculator was developed for a specific region using land use, crop type, irrigation activity in the form of drip or sprinkler, on-farm development and activity, improvement in the irrigation application tools, and so on. Thus, it is region-specific but can be developed for other regions as well. Besides GMID, the calculator has wider use in providing water use efficiency information for irrigators as they plan changes to their farm irrigation systems. It can be used as a decision support tool for irrigators to compare water use efficiency merits of technologies and practices they may consider adopting.

3.1.3 Reducing Water Usage through Sub-Surface Drip Irrigation

Submitted by: Ian Hamono (2019)

In the early 2000's Australia was enduring drought; water prices were high and reliable water supply was difficult to achieve. To combat the cost of water and the potential shortfall, the need was felt for an effective irrigation system that would maximise yield for each unit of water used, keep costs down, and maintain sustainability.

Considering the drought situation, a permanent and efficient irrigation system covering approximately 160 ha and including a subsurface irrigation system powered by an array of pumps, providing for a wide range of crops all year round, was implemented. The irrigation system comprised of developed drip tape with a longer life expectancy and a filter system to the pressurized pipe network (to remove all fragments from the water and prevent blockages). The automated filter system backflushed either on a time perimeter or due to a pressure drop across the filter.

The subsurface drip irrigation was pumped out of a dam supplied from the regional irrigation network. The Irrigation system was powered with two 55 kW three-phase electric motors that provided water to ten pod disk filters. The water was then conveyed via a 375 mm mainline to a series of in-field valves. Each valve supply to about 4-4.5 ha blocks. These field valves also had an inline disk filter on them, so in case of a filter failure on the primary filter, or some passing debris, it was collected in the field valves, and there is no chance of any debris getting into the drip tapes and blocking the emitters.

The drip line spacing varied depending on crop type; some were spaced a metre apart, some others were spaced a metre and a half apart. The field valves were controlled by a computer system in the main pump shed. The control system also controlled fertigation and the flushing of the main filter. It controlled the field valve function (ON/OFF).

The proposed irrigation system was applied in a 160-ha plot and compared the water used for irrigation and measured productivity using three differing irrigation methods, including Surface Irrigation and Centre Pivots. The subsurface irrigations using the pressurised pipe system had a water-saving of 1.5 ML/ha with an increase in crop productivity of about 1-2 tons/ha.

The underground irrigation system eliminated the need for channels, structures, check banks, and surface drains, thereby freeing about 3.5% of the surface land for cultivation. The most significant benefit was increased flexibility in irrigation practices, including applying small amounts of water to finalise crops when full irrigations were not required and the flexibility to apply the right amount of water at the right time to match water application to crop needs.

The technology demonstrated that having a control system for supplying irrigation water using pumps and filters controls not only the rate of supply of water but also controls the quality of water; ultimately saving irrigation water but also increasing crop productivity. The work created interest within the local irrigation district, and the knowledge was shared and extended to Agriculture Victoria. Regionally two of the most significant costs facing local irrigators were water and labour. Hence, an irrigation system that can increase production whilst decreasing water and labour use had much appeal. There has also been a shift to higher-value niche crops that required more precise water application, as provided by the technology.

The expenses on the machinery outweighed the benefits. The innovation had the potential for industrial development and private production, thus leading to job creation and industrial development, including private participation in agriculture.

Figure 3.3 Reducing water usage through Sub-Surface Drip Irrigation

3.1.4 Improving Water Use Efficiency in the Australian Nursery Industry

Submitted By: Lex Mc Mullin and John Mc Donald (2019)

Irrigation systems and management in production nurseries are complex, and the interaction of individual components requires careful management for the system to operate at peak efficiency. The value of nursery production in South-East Queensland was estimated at AUD 628.6 million (70% of Queensland production), with the remaining 30% (AUD 269.4 million) being produced throughout regional areas of the state, over a total production area of 2000 ha. This production supported horticultural markets with an estimated economic value of AUD 5.4 billion/annum. With the ever-increasing pressure on water resources, the requirement for efficient water usage and the development of tools to collate available resources like land and water management plans increased.

At the same line, a project focused on assisting growers (in the nursery industry) in the three priority areas of irrigation scheduling, irrigation design, and irrigation recycling was implemented with Queensland Government's financial support. The project evaluated the best cost/benefit in improving water use efficiency and productivity. The details of the project are provided below:

After thorough research, experimentation, and field evaluation for the Australian Nursery Industry, a range of nursery industry resources assisted growers in implementing water use efficiency measures by applying updated information and techniques.

Field officers used site visits to assist growers in addressing their unique issues, introducing a range of resources, and enabling growers to develop plans for improving water use efficiency. In addition to site visits, further technical information via technical articles, case studies, technical videos, workshops, field days, regular project updates, and industry trade events were also carried out for the growers' community.

Government funding also enabled the field offices to develop the tools further, improving and extending their usefulness. Growers are time-poor and rely heavily on information provided to them for decision making, rather than researching and testing information themselves. The tools and resources developed were used in guiding growers along with the necessary guidance from a field officer to implement and adopt.

Figure 3.4 Field visit

The three priority areas and their related techniques covered under the project are:

1. Irrigation scheduling: Irrigation scheduling can significantly improve water use efficiency whilst incurring little or no capital cost. During the project, growers used simple tools to schedule their irrigation more accurately, such as monitoring evapotranspiration or container weight. A container weight-monitoring tool (Portable Weight Based Scheduling Unit – PWBSU) was used to enable the changes in container weight to be displayed on a graph, giving a visual representation of the changes in the moisture content of the growing medium growers. - The information generated from the PWBSU was used to discuss possible changes to irrigation scheduling and fine-tune irrigation scheduling for each business. Evapotranspiration from a weather station installed onsite was also calculated and displayed on the graph. Growers were then able to use this to guide future irrigation scheduling decisions.

The characteristics of the growing medium had a significant influence on irrigation management. Guidelines on the water holding capacity of different growing media types and how they affect irrigation scheduling were used in discussions with growers and in conjunction with the PWBSU data.

2. Irrigation Design: From previous research work, irrigation design guidelines were developed to design nursery irrigation systems to improve water use efficiency. In addition to this information, a database of sprinkler design performance was available to assist growers in determining the efficiency of an irrigation design or compare the efficiency of design options.
3. There were specific requirements for uniformity and application rates for containerised nursery production irrigation systems. Previously developed guidelines recommended that sprinklers be laid out in a square pattern, at uniform spacing, with sprinklers located around the perimeter of the irrigated area, and efficiency parameters for Mean Application Rate (MAR < 15mm/hr), Coefficient of Uniformity (CU >85%) and Scheduling Coefficient (SC < 1.5) to be used as the best management practice (BMP) benchmarks. These guidelines formed the basis for assisting growers in upgrading and designing new sprinkler irrigation systems during site visits and discussing available options.
4. A major factor in determining the MAR of the system is the knowledge of the absorption rate of the growing media and its influence on water use efficiency. Previous research identified absorption rates for different growing media types of < 15 mm/hr for bark-based growing media, < 20 mm/hr for bark-based media with wetting agents added and < 25 mm/hr for coir growing media.

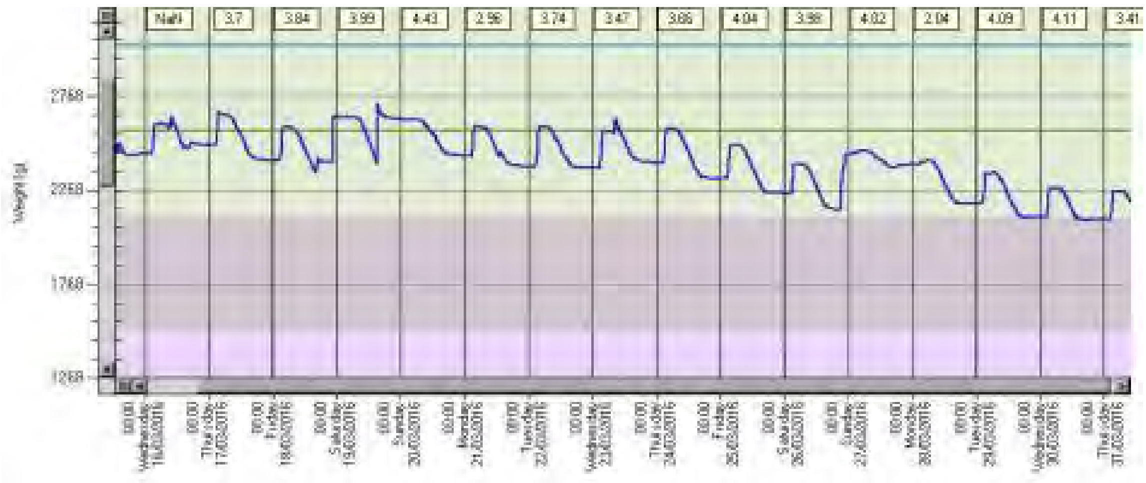

Figure 3.5 PWBSU graph

A database of modelled sprinkler performance (MAR, CU & SC) enabling emitter information was provided with a schematic outline of a proposed irrigation design. It was used to guide growers as to the expected performance of a sprinkler design, and poorly performing systems were replaced with high-efficiency designs.

Recycling: The containerised nature of most production nurseries means that any water that does not get to a pot fall onto the production surface and can potentially be collected for reuse, but this method may incur significant capital costs. Site visits and information resources provided information on designing and installing recycling and treatment systems. Significant issues with using recycled water are the control of plant pathogens and monitoring of water quality; several technical articles providing information to growers on the performance of different treatment systems and the nursery production BMP (NPBMP) guidelines were used as the primary information source. In addition to the NPBMP guidelines, several case studies, technical articles, and video resources were used to promote this message and provide data to growers on managing recycled water.

Changes to irrigation scheduling enabled water savings of up to 55%, with little or no capital outlay for growers. A project retrofitting Best Management Practice (BMP) sprinkler layouts in existing businesses identified annual water savings of between 6.5 and 9.4 ML/annum or a 24-43% reduction in water usage per annum. Recycling drainage water from nursery irrigation can provide maximum water savings (up to 81% savings measured).

Hand-watering was shown to be an inefficient irrigation water application in both water use efficiency and productivity; therefore, drip irrigation systems were recommended to improve water use efficiency. A drip irrigation assessment and an evaluation tool were used to demonstrate to growers how these systems should be set up to achieve maximum water use efficiency.

This technique calculates the optimum water requirement and monitors the water supply following the assessed optimum need. Any extra water so supplied is recaptured and recycled. The water use efficiency is therefore maximised.

The replicability of such a technique is simple to adopt. Extrapolating data to the entire Australian Nursery Industry, similar programs could achieve water savings of approximately 8 MCM across Australia, along with ongoing savings in subsequent years. Further, the techniques used in this project apply to any containerised nursery throughout the world, showing the worldwide potential of the innovation.

3.2 BRAZIL

3.2.1 Expansion of the "Mandacaru Methodology" for Efficient Irrigation

Submitted by: Rodrigo Ribeiro Franco Vieira and Frederico Orlando Calazans (2017)

Expansion of the "Mandacaru Methodology" for Conversion of Irrigation Parcel Systems was conducted in 2010-11 as a pilot project. The results on water saving, power saving, increase in productivity, and environmental benefits allowed further expansion to more than 404 irrigated perimeters. It converted irrigation systems from furrow to trickle at *Mandacaru* Irrigated perimeter in *Juazeiro, Bahia* state in Brazil. The objective was to save both water and power for pumping the required water. Combining these activities reduced labour costs and increased productivity, and the protection against environmental damages. Approximately 17% water use efficiency was achieved. This led to a 52% reduction in the annual volume pumped, 36% energy-saving for the perimeter management, reduction of labour cost, and the full utilization of the farmland up to 100% (which was between 50 and 65% earlier).

The details on the methodology and results are provided below:

The system was designed for temporary crops, drip irrigation, pasture, sprinklers, permanent crops (fruits), and micro-sprinkler, depending on the crop type. Some farms had three methods of irrigation for the same individual pump. In addition, each farmer had Individual Pump Station (IPS) and the responsibility to use the water optimally. The water from individual reservoirs was pumped to the emitters, controlled by automatic panels and hydraulic valves.

Water Balance (WB) of each parcel based on the cadastral records, analysis of the current (furrow) and future (pressurized) situations established the unit flows (weighted average of all crops in the lot), and total for each farm was prepared. Reducing coefficients (KL – KELLER / BLIESNER) were also calculated to reduce the volume required, emphasizing that the concept of conversion was of high-frequency trickle irrigation.

The emitters for each crop (flow, spacing, pressure) were designed so that the total application time and the final unit flow rate do not exceed that provided for in the water balance. This was essential for the design and was the most challenging stage.

Adoption of high-frequency irrigation, helped by automation devices, allowed the soil moisture monitoring to avoid excessive application, which was difficult in furrow irrigation. IPS (the energy company) added one more element to the production chain: which was, and in case of no payment, energy was cut; energy fee led to the critical use of water and eliminated the application of excessive water. Farmers also realized that productivity and quality could be improved by using less water, which provided better prices on the market and increased adaptation rates.

Once implanted, the data obtained over the years was even better than the ones initially calculated (52% reduction of the annual volume pumped, 36% energy-saving for the perimeter, and environmental benefits), such as the increased yields of the annual crops by up to four times, as well as the re-utilization of salinized and previously considered useless soils.

Subsequent results of these four perimeters indicated that the total volume of water saved in these four perimeters was 79,218,397 m^3 which is more than 27% of the average water used (saving of 63%), and the average saving in annual energy was 39.75%. The following graph shows that the adopted innovation of drip irrigation resulted in decreasing irrigated areas using other methods.

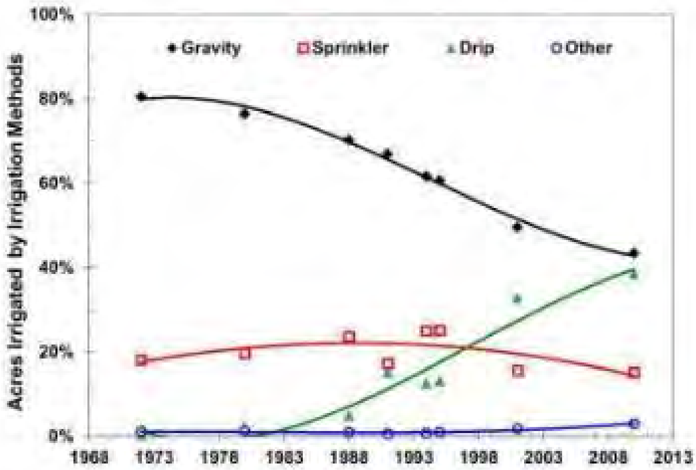

Figure 3.6 Conversion from gravity to Trickle irrigation at USA (Snyder, R.)

3.2.2 Controlled Water Stress: Improving Coffee Production and Quality Saving Water

Submitted By: Antonio Fernando Guerra (2012)

Cerrado region in Brazil is responsible for approximately 40% of national coffee production. It is necessary to increase the yield and coffee quality to maintain sustainability and competitiveness. Therefore, an appropriate technology was required to support the essential improvements in the existing production systems. One such research study applied controlled water stress just before the flowering period to synchronize buds' development and obtain a high percentage of berry fruits, increasing yield and coffee quality.

The research was carried out in the experimental field of the Brazilian Agricultural Research Corporation. A centre pivot irrigated the area on 8 ha and 2-ha area without irrigation. The irrigated area was split into four quarters of 2-ha to test four irrigation regimes. The soil of the experimental area was classified as a Clayey Dark Red Latosol. Coffee trees were submitted to five irrigation regimes: irrigation all over the year when soil water potential reached -0.5 MPa (IR1); irrigation suppression from June 24 until leaf water potential reached -1.2 Mpa (IR2) and -2.2 Mpa (IR3); supplemental irrigation after blossoming be induced by rain (IR4) which resulted in mean leaf water potential of -3.4 Mpa and without irrigation (IR5) when leaf water potential reached values below -4.0 Mpa. Soil water content was measured using profile probes and leaf water potential at pre-dawn with a Sholander-type pressure pump. Leaf water potential readings were done between 3:00 and 5:00 a.m. Coffee trees were spaced 2.8 m between lines and 0.5 m between plants. Water was applied, and coffee trees extracted around 50% of available water in the upper 0.40 m soil profile. Soil water content was measured in the soil profile of 1-meter depth by using a Profile Probe Delta-T. The amount of water applied by irrigation was calculated to raise the soil water content of the upper 0.40 m profile to field capacity condition (-0.008MPa). Experimental plots were harvested manually at once, and ten samples of 100 fruits were taken to measure the percentage of green, berry, and dry fruits. The plot's production was dried in a cemented patio until grain humidity reached 12% to estimate gross grain yield. Coffee grains were pealed to obtain processed coffee yield and coffee grains sieve and type classification.

The results showed that suppression irrigation from June 24 until leaf water potential reached -2.2 MPa on September 4 was the best treatment for bud's development synchronization. In this treatment, flowering uniformity reached values higher than 85%, and the production of berry fruits at harvesting was up to 83%, optimizing the potential for producing high-quality coffees. The higher yield reached around 78 bags of 60 kg/ha of processed coffee. It occurred in mild (IR2) and adequate water stress (IR3) treatments. A significant reduction in yield was observed in the treatments irrigated all over the year and when plants were subject to intensive water stress. Adequate water stress promoted high yields and guaranteed an intensive and uniform flowering period at the beginning of September, when maximum and minimum temperatures were suitable for this process, producing viable pinheads. Also, the reduction in the percentage of green fruits at harvest, which did not complete the filling process, contributed to the higher yields observed in the IR3. Controlled water stress creates sustainable irrigated coffee systems and reduces pressure on the water and energy use during the dry season. Irrigation management strategy using controlled water stress increases yield and grain quality and reduces irrigation costs.

3.3 CHINA

3.3.1 Water and Salt Regulation Scheme Under Mulched Drip Irrigation for Cotton in Arid Regions

Submitted By: Dr. Tian Fuqiang (2019)

Secondary salinization induced by improper irrigation is recognized as a threat to agriculture worldwide, especially in arid and semi-arid areas. Secondary salinization is typically caused by flood irrigation because of the rise in the water table and the subsequent intense phreatic evaporation leading to an upward movement of salt contained in the groundwater, which ultimately accumulates in the surface soil. Utilizing micro-irrigation techniques also leads to an increase in salinization, but in this case, secondary salinization is caused by insufficient leaching due to inadequate watering, as demonstrated by Figure 3.7. An increase in salinization resulting from drip irrigation techniques has occurred in many dry areas, including Israel, Egypt, the United States, Lebanon, China, among others.

Figure 3.7 Demonstration of secondary salinization induced by drip irrigation. Left: Salt accumulated on surface soil of cotton fields indicated by white colour; Right: Salt rings formed on soil surface due to evaporation of saline irrigation water from drip irrigation of grapes

Mulched drip irrigation (MDI) incorporates surface drip irrigation methods combined with film-mulching techniques, saving water and labour while increasing crop yield. This study developed a numerical model of soil water and salt movement under MDI conditions. Guided by experimental data and numerical simulations, soil water and salt distribution patterns at multiple spatio-temporal scales were ascertained. An optimal irrigation schedule for the cotton-growing season coupled with comprehensive soil water and salt regulatory scheme for MDI was developed in an experimental research station in China. The model demonstrated high computational efficiency and robust numerical stability, making it suitable for long-term continuous soil water and salt migration simulations under drip irrigation.

Irrigation quotas and intervals are two essential parameters of the mulched drip irrigation system. From field experiments and theoretical analyses, it was found that crop yields increase with irrigation quotas within a set range of water volumes. However, water use efficiency tends to decrease. An optimal irrigation interval for a fixed irrigation quota maximizes water use efficiency. This allows the determination of an optimal irrigation schedule based on the integrated water and salt stresses index. A holistic water and salt regulation scheme for MDI cotton fields was developed by integrating an optimal irrigation schedule during the growth period, a flush scheme during non-growth periods, and a salinity reduction scheme of applying chemical ameliorants. This innovative technology has been extensively applied to a 20,000-ha region of cotton fields, resulting in the saving of 500 MCM of water.

During the growth period, water-saving was achieved by using optimizing irrigation systems and improving the utilization efficiency of irrigation water. During the non-growth period, through flush irrigation scheme, yearly flush irrigation was replaced by a multi-year flush irrigation scheme, and the flush irrigation quota was reduced compared to traditional methods. The amount of water used for salt leaching was also reduced. Additional water savings were also realized by reducing the amount of salt leaching water through chemical ameliorants. Compared to traditional irrigation methods, about 25% less water was required with the water and salt regulation scheme. Also, the cotton yield increased by 17% with stable soil salinity.

Proven to be one of the significant agricultural technologies for saving water and increasing crop yields, drip irrigation technology has been applied on a large scale in the north-western and north-eastern regions of China and other Central Asian countries. This technology has broad application prospects, especially in China and Central Asia, where more than 70 Mha of cotton is grown. It is estimated that promoting this technology can generate more than 7 billion USD each year and save up to 17.5 BCM of water resources. It also has played an essential role in regional economies, social development, and poverty reduction. The technology demonstrated that non-conventional and systematically calculated irrigation water requirements not only save water but also help in increasing the crop yield, and it applies to a variety of crops.

Figure 3.8 Experimental Station in Xinier Town, Xinjiang Uygur Autonomous Region

3.3.2 Innovation and Extension of Sprinkler and Micro-irrigation Technologies in China

Submitted By: Prof. Li Jiusheng (2016)

Irrigated farmland contributes approximately 75% of grain and more than 90% of vegetables produced in China. Unfortunately, the increasing water scarcity coupled with population increase and climate change has aggravated food security issues. Newly designed sprinklers and micro-irrigation systems have been implemented in China to improve the situation.

Following are the specific cases and findings reported after the implementation of these sprinklers:

1. Consumption mechanism of sprinkler water intercepted by the crop canopy: Lack of knowledge on canopy interception led to farmers' hesitance in adopting the technology. Studies were conducted between 2001 and 2010 to quantify the amounts of canopy interception for sprinkled crops and investigate their consumption mechanism. Results indicated that the interception varied with growing stages from 0.7 to 3 mm for winter wheat and 0.8 to 2.6 mm for maize. Moreover, the evaporation of water intercepted by canopy compensated for partial loss of sprinkler water as the plant transpiration and soil surface evaporation could be suppressed by increased humidity and reduced temperature within the sprinkled field resulting from the evaporation of the water intercepted. Through energy balance measurements (Bowen ratio and eddy covariance methods) and modelling, the net losses were separated from the gross losses and quantified to be 4.3-6.5% of the water applied during the irrigation season of maize and approaching zero for winter wheat. The net losses accounted for a relatively small portion of water applied, confirming the water-saving merits of sprinkler irrigation. Thus, a software package was developed to determine net loss under varying environments and operation conditions of sprinkler irrigation systems.

2. Droplet size distributions from sprinklers: Droplet size distribution is an important parameter that controls evaporation loss from spray and soil erosion caused by droplet impact. Extensive measurements and modelling of droplet size distributions from different shaped sprinkler nozzles were conducted. These works significantly contributed to developing and revising Chinese national technical standards of sprinkler irrigation.

3. Design standards of sprinkler uniformity: Based on field observations, a sprinkler uniformity lower than the value suggested by the current standards (C_u = 80%) was recommended to reduce sprinkler irrigation systems' installation and operation costs. A non-uniform distribution caused lateral and vertical redistribution of water and solutes in soil. These findings were adopted to develop and revise the Chinese national standards related to sprinkler irrigation.

4. Variable rate irrigation for centre pivots: Variable rate irrigation (VRI) is an emerging efficient irrigation technology to determine the optimal cycle time of solenoid valves at specific travel speeds of the pivot. The traits of the VRI system in enhancing water use efficiency and reducing deep percolation were evaluated for winter wheat and summer maize in the alluvial flood plain of China. VRI reduced irrigation water use by 17.6% during the irrigation season of maize and reduced the variability of deep percolation within the entire field. Fieldwork suggested that AWC (available water holding capacity) can be an alternative parameter for zone identification in VRI management.

5. Design of landscape sprinklers: The study assured that the arc-controlling unit of sprinkler rotation stays in place and undamaged when the sprinkler was accessed or driven by casual or misoperation, thus increasing sprinklers' service life and stability.
6. Transport of water and nitrogen in soil under drip fertigation: The study addressed the concerns of potential toxic rhizospheric environments caused by fertigation. The research included design and operation strategies for injectors, laboratory and fieldwork on nitrogen in homogeneous and heterogeneous soils, and the response of plant growth and crop yield and quality to water management practices and fertilizers under surface and subsurface drip irrigation
7. Design standards of drip irrigation system uniformity: Extensive investigations were conducted on the influence of drip irrigation uniformity and spatial soil variability on the dynamics of water, nitrogen, and salts, as well as crop yield and quality under a wide range of environments from arid to sub-humid for cotton, maize, and vegetable crops. It was found that the effect of drip irrigation uniformity on crop yield and deep percolation of water and nitrogen is less than expected. It was concluded that micro-irrigation system uniformities as low as 60%, although lower than the current standards, may be acceptable in yield and nitrate leaching; and a lower uniformity coefficient can be used in the humid and semi-humid regions than in the arid regions.
8. Efficient and safe utilization of reclaimed sewage effluent through micro-irrigation: With the increasing use of reclaimed sewage effluent in irrigated agriculture, experiments were conducted to study pathogens behaviour in the soil-plant system. It was found that the potential pollution risk of E. coli to soil can be reduced. Using the 15N tracing technique, the effectiveness of nitrogen-containing in sewage to crop production was also quantified, and No E. coli uptake was detected when drip irrigation was used.

A management practice at 100% ET_C (evapotranspiration) and a nitrogen application rate of 160 kg/ha were recommended and widely used in the region. On average, the requirement of seasonal irrigation and fertilizers reduced by 20-30% and 15-20%, respectively, compared to traditional surface irrigation. Studies revealed that increasing frequency from conventional monthly fertilization to weekly fertigation for greenhouse vegetable crops could increase yield by 18% and reduce nitrogen usage by 15-30%. The three years of field experiments in the sub-humid region of Northeast China revealed the advantage of plastic mulch in saving water by 10-15% via reducing evaporation from the soil surface and enhancing crop growth through increasing soil temperature at the beginning stages of maize. Using two or three in-season fertigation splits could meet crop nutrient requirements on time, thus increasing crop yield by 5-10% and reducing the need for nitrogen. The estimated Water-Saving was about 180 MCM in the three years of the experiment.

These technologies, mainly sprinkler and micro-irrigation, were extended to around 60,000 ha in several provinces covering winter wheat, maize, and several vegetable crops. Approximately estimated acreage of direct use was about 1,200 ha with total water savings of about 3.7 MCM and fertilizer reduced by 270 tons. Drip irrigation has become an acceptable method for greenhouse vegetable crops in China. The developed management practices were used in 330 ha of maize cultivation (10 centre pivot installations) from 2012 to 2015. The estimated total accumulative water-saving was 1.6 MCM in the three years. It was further extended in two counties of *Heilongjiang* Province from 2012 to 2015, with a total acreage of about 3,400 ha maize irrigated by centre pivots. The amount of water savings was about 70 m^3/ha, with a total estimation of 14 MCM. Currently, the number of centre pivots and linear move systems in China has reached 7,000 installations with a total area of 40,000 ha. These management practices are planned to be implemented in a larger area, and more water and fertilizer savings can be expected. These sprinklers contributed to the domestic industrialization of landscape sprinklers and water and soil conservation for landscape irrigation in China. They were also exported to the USA, Brazil, Mexico, Iran, and other countries. The findings provide a complete guide for designing, managing, and evaluating micro-irrigation systems to maximize their benefits.

3.3.3 Water-Saving, Pollution Prevention and Emission Reduction of Paddy Rice

Submitted By: Mr. Li Xinjian (2015)

After three decades of research, the controlled irrigation methodology was introduced in paddy growing fields of Guangxi province, China, to overcome contemporary challenges. The technique includes an optimal combination of irrigation timing, frequency, irrigation control of water level in the field, and the amount of fertilizer.

China has a large output of paddy rice with an area of 461 million mu and an output of 185 MT, ranking second and the first in the world, respectively. Guangxi, the largest growing base of sugarcane in China, has a mango growing area of 900,000 mu and is also one of the most suitable places to produce black tea, green tea, and Oolong tea. It has 1,500,000 mu tea gardens and 2,400,000 mu citrus growing area. Despite the rich rainfall and water resources in South China, the highly uneven distribution of yearly rainfall led to an ever-increasing water shortage, weak infrastructures, insufficient innovating capacity, and low awareness of water-saving irrigation technologies. Most farmers lack the basic knowledge of selecting the time, amount, number, and mode of crops for irrigation. In South China, paddy fields are traditionally watered through flood and plot-to-plot irrigation with the help of gravity. The fields are inundated for long periods, leading to plant diseases and pests, unproductive tiller weak stem, and lodging, resulting in yield decline. Secondly, with annual water consumption reaching 12,000-15,000 m^3/ha, the conventional irrigation method leads to water wastage and consequent farmers' disputes over water sharing in dry seasons. To boost outputs, farmers have been applying fertilizers, pesticides, and herbicides in large quantities, leading to contamination of surface water and shallow groundwater.

After more than three decades of experimentation and studies at the Guilin Irrigation Experimental Station, a controlled irrigation methodology was devised to address these problems. The controlled irrigation technique for paddy rice develops an optimal combination of irrigation timing, frequency, water, the water level in the field, and fertilizer. The technique was promoted on 15.3 Mha in the region resulting in 28.7 BCM of water savings from 1990 to 2013. The innovation focuses on water content production, irrigation principles, temporal and spatial changes, recycling rural sewages through fast infiltration, the general wetland system, and farmland irrigation. It revolves around the connection of physiological water demand of paddy Rice, field water consumption, water, and fertilizer coupling, channel irrigation management, and ecological repair. This technology addresses four indices of the paddy rice irrigation system from the perspectives of water resource, environment, and management, i.e., irrigation time, irrigation number, irrigation quantity, and irrigation quotas which correspond to the total quantity control and quantity management technology adopted in the process of soil testing formula, fertilization time, fertilization number, fertilization load, and channel management.

As a result of these techniques, in an area of 667,000 ha with 1872 m^3/ha under paddy, up to 1.25 BCM of irrigation water was saved cumulatively; crop yield increased by 300 kg/ha and 200,000 tons cumulatively, and farmers' income was increased by 900 yuan/ha and 600 million yuan in total. From 1990 to 2013, the cumulative water-saving in *Guangxi* Autonomous Region amounted to 28.704 BCM; total crop yield growth added up to 4.6 MT; and the income growth totalled 276 billion Yuan, while the consumptions of fertilizer fell by 2.3 MT, and nitrogen and phosphorus elements washed away dropped by 30%. The emission of non-point source pollution was reduced by 26 BCM.

Field surveys were carried out in the countryside in the irrigation zone and selected 240,000 mu farmlands in *Pingle* and *Lipu* counties as the pilot zone for water-saving paddy rice irrigation. Significant achievements were made in the same year. The water consumption of late rice in *Lipu* was 290.5 m^3/mu with scientific irrigation. In contrast, the water consumption was 377.5 m^3 in the conventional deep-water submerged irrigation, saving about 89 m^3/mu. The output increased to 462.8 kg/mu from 399.4 kg/mu with scientific irrigation, increasing by 63.4 kg/mu. According to domestic experts, the incremental output is 25.4 kg/mu with scientific irrigation based on a ratio of 0.4. In *Pingle* County, the incremental output was 24.2 kg/mu.

Pilots were also conducted for the cultivation of sugarcane, mangos, tea, and citruses in *Liuzhou, Laibin, Nanning, Chongzuo,* and *Baise* of Guangxi Province, with a cumulative promotional area of 3 million mu; saving water and fertilizers by 36,000 m^3 and 45 million kg cumulatively and respectively and increasing incomes by 4.5 billion yuan.

The water-saving irrigation technology was mainly characterized by a combination of drip irrigation, micro-irrigation, and soil testing formula fertilization in the implementation of sugarcane, mango, tea, and citrus in an area of 3 million mu. The economic and social benefits from the irrigation experiment were obtained every year since the 1960s. In 1992 and 1993, 1.78 Mha of rice field was spread with the "shallow water, wet and dry irrigation method" in the *Guangxi* region. The total water saved was 2.53 BCM, and the total increased rice yield of rice was 672000 tons in two years. The average value of saving water was 1.42 tons/ha, and the average value of the increase in yield was 377.1 kg/ha. The total direct economic benefit was 543 million RMB, with an average direct benefit of 304.5 RMB/ha. Eighty-six countries, 922 townships, 1132 irrigation districts, 6302 villages, and 25 million framer families were involved in the project implementation and benefitted from the technique.

3.3.4 Thin and Exposed Irrigation

Submitted By: Prof. Yi Yongqing (2013)

Water scarcity is a big crisis in South China. Focus on water conservation using simplified and scalable technology is a necessity. The canal linking, thin and exposed irrigation for paddy, economical sprinkler, and other micro-irrigation are some of the water-saving technologies implemented and studied in a research area. In the agricultural area of 5.11 Mha of farmland, 5.15 BCM of water was saved, 1.58 billion kg of grain increase was witnessed, and 0.30 billion KW of power was saved using these technologies. Besides ecological benefit, the direct economic benefit was RMB 11.98 Yuan.

To overcome deficiencies of the conventional long-standing irrigation water practice in paddy cultivation thin and exposed irrigation method was suggested, whereas “thin” refers to a thin irrigation layer (around 20 mm) and “exposed” refers to field surface being exposed to the air to absorb oxygen and emit harmful gases. It was found that if there is water in the root system, the paddy can grow normally. Even though the straw was not inundated by water and the yield was very high. With no-water layer irrigation, the soil moisture in the field was kept at 100% only in the striking root period. The soil moisture was then kept between 70% and 95% to make full use of precipitation and two to six times of irrigation, while there was no water layer on the filed surface. The average irrigation quantity for flood irrigation is 1000 m^3/ha; however, thin and exposed irrigation saved up to 53% of irrigation water. The yield increased from 685 kg/ha in case of flood irrigation to 1080 kg/ha. The water productivity with the new technology was 2.8 kg/m^3.

Another contribution was developing low-cost sprinklers by reducing the material cost through “economical sprinkler and micro-irrigation”. Furthermore, the idea of “miniaturization of irrigation unit” emerged. The irrigation unit is the irrigation area covered by one pumping station. The cost for pipes accounts for 50% to 60% of the total expense, and the cost of the pipes is determined by the diameter, while the rotation area determines the diameter of pipes. After theoretical calculation and consultations, the rotation area was controlled around 0.67 ha, with 15 rotations. The controlled irrigation unit area was around 10 ha, and the farmers managed the system within a radius of 400 m. The idea brought forward the conception of “permeable lift loss hgp”. The typical approach was to design the sprinkler and micro-irrigation and finally calculate the total lift (H) of the system. Low-cost sprinklers made using PE pipes reduced the overall costs making this technology more economical. The cost was cut down to 50% leading to its further extension.

Thin wall and multiple holes sprinkler hose replaced the micro-sprinkler nozzle, saving around RMB 45,000-6,000 yuan/ha. Thick walls of drip irrigation tubes were replaced with thin walls and then reduced the waste of pipe materials caused by the blocking of drip holes. Finally, the expensive fertilizer applicator was replaced with the simple negative pressure absorption instrument of pumps.

The technology was widely implemented in *Yuyao* municipality. In 1990, three different canal lining types were developed based on different groundwater tables and soil types. Special water plugs with steel wire meshed concrete pipes were used in the thin walls. Since 1994, this technology has been extended in *Zhejiang* province over 4.20 Mha, where 3.91 BCM of water and 0.26 billion KW of power were saved, and 1.45 kg of grain has been increased. The economic benefit was RMB 3.63 billion Yuan.

In 2008, the Chinese Ministry of Water Resources, the Department of Irrigation and Rural Water Supply and China Irrigation and Drainage Development Centre, investigated the technology and approved its extension in China. In 2009, Zhejiang provincial government extended it over 67,000 ha of farmland in *Zhejiang* province. So far, this technology has been extended in over 6,30,000 ha of farmland and 1,55,000 ha of livestock farms in South China. It saved 0.94 BCM of water, and farmers’ net income was increased by RMB 7.25 billion.

By the end of 2012, this technology was extended in over 2,80,000 ha of farmland, saved 0.30 BCM of water, increased 0.13 billion kg of grain, and saved 34 million KW of power; the direct economic benefit was RMB 1.1 billion yuan. It can be seen that water-saving could be achieved by assessing the soil moisture at the root level and determining the right water requirements, thereby changing the conventional method of flood irrigation with limited supply to sprinkler technology, making it more affordable and available for multiple users. Over and above these land farm applications developed the supply-side infrastructure, and the conveyance losses were reduced to a large extent, and the concept of piped irrigation was established.

3.3.5 Theory and Technology of Controlled Irrigation of Rice in China

Submitted by Prof. Peng Shizhang (2012)

Food security is facing the challenge of severe water scarcity in China. Agricultural non-point source pollution caused by unreasonable irrigation and drainage management is increasing in intensity. In China rice is a major staple food crop and is grown on 30 Mha. With rapidly growing sectoral demands, the Government has invested and promoted various water-saving technologies like the Controlled Irrigation Technology. The technology saves irrigation water, increases grain yield, enhances rice quality, reduces agricultural non-point pollution and greenhouse gas emission from paddy fields.

Controlled irrigation (CI) is a new and widely adopted water-saving irrigation technology for rice cultivation in China. The concept of rice-controlled irrigation defines the lower limits of root layer soil moisture in different growth periods and forms a practical model of CI technology. The irrigation thresholds of the technology were determined based on the sensitivity of rice to soil moisture conditions and water requirements at different growth stages. A set of field characterization indicators for different rice growth stages were established. For example, when the tread does not trap the foot and cracks of about 10 mm wide appear in the paddy fields during the late tillering stage, irrigation should be applied until the soil moisture reaches saturation level in the observed root zone. After the crop's regreening stage, there is no need for ponding water. In case of rainfall, flooded water up to 5 cm depth can be maintained for less than five days to take full advantage of the rainfall. In large irrigation districts, CI technology can be implemented based on managing the irrigation frequency and irrigation duration.

Under CI technology, the transpiration and evaporation of rice were reduced by 20.7-43.8% and 7.9-21.9%, respectively, compared to traditional irrigation. Similarly, seepage and water use in paddy fields were decreased by 38.4-61.4% and 29.4- 36.9%, respectively, compared with traditional irrigation. Rice yield and water use efficiency increased by 3.2-12.4% and 47.4-74.1%, respectively, compared with conventional irrigation.

Application of the CI technology not only leads to a reduction in irrigation water, increase in yield, enhancement of rice quality, but also results in the reduction of nitrogen, phosphorus losses, and methane emission from paddy fields by 80%, 65%, and over 80%, respectively. The efficient irrigation and drainage mode has been widely applied in rice irrigation districts of *Jiangsu* Province, and *Heilongjiang* Province, and *Ningxia Hui* Autonomous Region in China. A cumulative 4.46 BCM of irrigation water was saved because of the efficient irrigation and drainage technology. The accumulated total benefits were increased by 2.08 billion yuan.

From 1991 to 1995, the CI technology in rice was widely applied in the *Xiaobudong* irrigation district and the *Nansihu* irrigation district in *Shandong* Province. While the application area reached 33,300 ha, the irrigation water was reduced by 120 MCM, and the accumulated total benefits were increased by 2.82 million yuan. The technology was widely applied in the irrigation districts of *Beijing* suburbs, *Shanghai* state farms, *Hunan* Province, *Jiangxi* Province, *Anhui* Province, *Hainan* Province in China.

Subsequently, the technology was promoted in the *Ruhai* irrigation district, *Jiangdu* irrigation district in *Jiangsu* Province, the *Qingtongxia* irrigation district in Ningxia Hui Autonomous Region, and the *Ganfu* Plain irrigation district in *Jiangxi* Province of China. The cumulative saved irrigation water was by 4.46 BCM, and the accumulated total benefits were increased by 2.08 billion yuan. In *Ningxia Hui* Autonomous Region, the accumulated application area reached 95,600 ha. The irrigation water was reduced by 580 MCM, and the accumulated total benefits increased by 98.04 million yuan. The total yield was increased by 48.94 million kg.

Overall, the CI technology has been adopted over 3 Mha of rice grown area, saved about 9 BCM of water, and increased the rice grain production by about 1.6 MT, annually. This integrative water-saving mode of rice irrigation district can be applied to more than 5.33 Mha in the northern rice grain-producing areas in *Heilongjiang, Jilin,* and *Liaoning* provinces, and can be widely applied in mid-eastern provinces in China (*Jiangsu, Zhejiang, Anhui, Jiangxi*, etc.) to achieve a comprehensive extension. The expected applied area of technological achievements can reach about 16.7 Mha, more than 50% of China's rice fields.

Figure 3.9 Demonstration guidance and on-site training by Prof. Peng Shizhang, practical way to implement controlled irrigation is to observe the compaction level and picture from the field

3.3.6 Innovation and Integrated Application of Buried Self-Lifting Devices for Water-Saving in irrigation

Submitted by: Chongbao Xie (2018)

China is facing an acute shortage of water resources and farmland, affecting its food production. On top of it, the significant lack of labour restricted the development of modern agriculture. Therefore, high-efficiency water-saving irrigation technologies like sprinkler irrigation, micro-irrigation, and irrigation with pipe conveyance are used extensively; however, their operation requires technical expertise like assembling and disassembling for irrigation every day. Further, the overland equipment interferes with the farming machinery. Thus, a need to develop a new irrigation technology was felt; one suitable for tillage saves labour and water and has no farmland occupation.

To fulfil this need, a buried self-lifting irrigation device was invented to overcome the shortcomings of fixed irrigation devices. The irrigation equipment is buried under the tillage layer when it is not working. Some of the device's modalities are presented below:

Based on the principle of reducing the shear strength of wet soil, the design theory of buried self-lifting irrigation devices was developed. Water ejection at the top of the device rapidly increases the soil moisture content leading to a quick reduction of soil shear strength. The device is lifted under force by the water pressure in the pipe. According to the force analysis of the buried self-lifting equipment, the maximum resistance and effective driving force in the self-lifting process, and the minimum inlet pressure formula for multi-type soil condition is calculated. The effect of the riser diameter on the minimum inlet pressure is also studied.

When the device is underground and begins to rise, a water jet ejects at the top of the device, and the soil moisture content increases while the soil shear strength decreases rapidly. At the same time, the riser is pushed upward by the force of water pressure, that is, the driving force. The effective driving force for breaking soil W (i.e., the upward force of water flow) is calculated by effective water pressure at the top of the riser multiplied by the cross-sectional area S1 of the riser. Among them, the effective pressure at the top of the riser is estimated by P0-PS-PW, in which P0 is the water pressure at the bottom of the system; PS is the local pressure loss at the nozzle outlet, and PW is the pressure of the water column in the riser and the casing. The effective driving force W is related to the inlet pressure, local hydraulic loss, length, and the cross-sectional area of the riser and the casing. When soil resistance is reduced to a value lower than the sum of the effective driving force, the friction force between soil and the riser and the gravity of the riser is gradually destroyed, and the device is lifted over the ground.

The new hydrants are classified into four kinds. They are buried self-lifting hydrants for drip irrigation, buried self-lifting hydrants for sprinkler irrigation, buried self-lifting hydrants for irrigation with pipe conveyance, and universal buried self-lifting hydrants. The main bodies of these devices are made of plastic and can be directly buried under the tillage layer. Before irrigation, these devices can automatically rise above the ground under the design pressure. Easily connected to facilities to supply water, these hydrants can be used in irrigation such as sprinkler irrigation, drip irrigation, and irrigation with pipe conveyance. In addition to developing the system of self-lifting hydrants, the modification in sprinkler nozzles was also carried out.

Four kinds of new products have been produced and used- a buried self-lifting micro-sprinkler nozzle, a buried self-lifting nozzle driven by steel ball-beating, a buried self-lifting nozzle driven by water pressure, and a buried self-lifting nozzle with several outlets. These nozzles are suitable for different water quality. By adopting reasonable driving force, transmission and channels, the nozzles can both achieve the function of being lifted above the ground and effectively protect soil particles from entering them. The buried self-lifting nozzles completely changed the recognition that nozzles could not be buried in the soil and solved the problems of the existing sprinkler.

Based on buried self-lifting hydrants and nozzles, a new integrated buried self-lifting sprinkler system was also researched and designed. This system is composed of a hydrant, telescopic coupling tube, and a nozzle. It is buried below the tillage layer when it is not working. The integrated buried system is pushed out of the soil before irrigation by water flow. It depends on the negative pressure of the water/sphere or manpower to push the system back below the tillage layer after irrigation. These new integrated, buried self-lifting sprinkler devices have been applied widely in *Hebei, Henan, Shanxi, Shandong, Beijing, Zhejiang,* and *Ningxia*.

Since 2012, these technologies and products have been used in more than 1.33 Mha of farmlands and saving water up to 2 BCM. The benefits of water and labour saving have been remarkable. From 2013-2017, more than 50 technology demonstration sites were spread throughout *Hebei, Henan, Shandong, Shanxi, Ningxia, Gansu, Inner Mongolia, Heilongjiang, Beijing, Zhejiang, Xinjiang,* and Tibet. The whole demonstrating area was over 2000 ha with a radiation area of over 26,000 ha and an application area of over 1.3 billion in the past five years.

3.3.7 Intelligent Precision Irrigation Control

Submitted By: Jiabing Cai (2013)

Intelligent Precision Irrigation Control (IPIC) is a tool that makes field irrigation decisions considering the relation of the relevant factors (soil, moisture, water) with the crop in the SPAC (Soil-Plant-Atmosphere-Continuum), to provide timely and feasible irrigation. It integrates the soil water contribution information, water deficit, and agriculture meteorology to make irrigation decisions, utilizing the intelligent arithmetic of artificial neural networks. Some of IPIC's characteristics are explained below:

The most critical point of IPIC is that the crop reference evapotranspiration could be estimated from the local weather forecast messages to make the irrigation management real-time. It is an auto-control irrigation system, which includes control software, a command tank, and an electromagnetism valve in the field. The system shares the database and reads it every 1 minute with the IPIC irrigation decision-making by the SQL server 2000. This is a real-time feedback mechanism. IPIC can also implement telecommuting through the website and IP technology to inspect the field application and irrigation control.

The tool is also more sensitive to reflect the water stress from crop physical responses versus old methods. The traditional method considered soil water content to make irrigation decisions. In IPIC, the irrigation decision is made from soil water and crop water stress diagnoses using an artificial neural network. This way more water is saved, and the crop reaches the optimum yield threshold. The crop water requirement is evaluated by observing soil moisture and other factors using the soil water balance equation in the crop root zone.

The core of IPIC is to evaluate the actual crop water requirement to supervise the irrigation management based on the diagnoses of the messages from the field. The innovation can be introduced and spread through special demonstrations in some well-appointed irrigation districts in China. The proposed methodology can be applied to a farmer advising service with low cost, thus improving irrigation efficiency. In the future, GIS and RS technology could be imported into the system to make the information more structured. Additionally, a monitoring and decision system of crop canopy temperature can be developed to calculate canopy-air temperature difference (CATD) and crop water stress index (CWSI) in real-time online.

There are an estimated 10 million irrigation districts that range from large, medium, and small size in China. There are 402 large irrigation districts with a scale that exceeds 20,000 ha. Of the medium irrigation districts, there are 5,300 with a scale between 666.7 ha and 20,000 ha, accounting for 15.5% of the total irrigation area in China. Water scarcity and drought during the 1990s were particularly severe, and in some areas, there was a crisis with water. Therefore, the state carried out a strategy of sustainable development, advocating the popularization of water-saving irrigation, and recommended adopting various water-efficient methods to make irrigation areas more productive than profuse.

The core of IPIC is to evaluate the actual crop water requirement to supervise the irrigation management based on the diagnoses of the messages in the field. It should be part of the named precision agriculture. The innovation will be introduced and spread through special demonstrations and further research in well-appointed irrigation districts. Then it would be applied in more irrigation districts. At the same time, the GIS and RS technology could be integrated in the system to make clear the differences in regions and times, which support the irrigation decision-making suitably.

3.4 EGYPT

3.4.1 Innovative Method for Rice Irrigation with High Potential of Water-Saving

Submitted by: Dr. Yousri Ibrahim Atta (2008)

Rice is one of the most inefficient crops in water use because it is conventionally grown under submerged conditions increasing the pressure on limited area resources in the country and contributing to irrigation water shortage during the peak summer season.

This study was performed to seek the possibility of growing rice variety (*cultivar Sakha 104)* on strips to decrease the amount of irrigation water and increase crop productivity. This method depends on reducing irrigated area by land division into furrows. The top of the furrow was named (border) and the bottom of the furrow was named (tape). Every border and tape were named (strip). The seedlings were transplanted at the bottom of the furrow using the same plant density as recommended into two rows of plants according to strip width. Irrigation was provided with enough amount for reaching the puddling stage then the next irrigation was given for tapes only with a depth of 7 cm. Accordingly, flooding area was less and consequently increased water-saving by about 30%-40%, and this new method also increased irrigation application efficiency and water productivity. However, it decreased percolation losses and reduced evaporation.

Two planting methods were followed in the permanent field: M1: Traditional transplanting: Transplanting of seedlings rice on flat at the hills (4-5 plants) distance of 20 × 20 cm to give the rate of (25 hills/m^2) and M2: Transplanting in strips of furrows 80 cm wide: (Top of furrow 45 cm and 35 cm for bottom). Seedlings were transplanted in hills (4-5 plants) 10 cm apart from the two rows on the strips keeping the same population as in the traditional method (25 hills/m^2).

The highest grain yield/ha (9.275 t/ha) was obtained from M2 treatment, while the lowest value was recorded from M1 treatment (8.789 t/ha). The results showed that the total water used by rice according to the different planting methods were 14,960 and 9,023 m^3/ha for M1 and M2 treatments, respectively. These results reported that water saved was about 5,938 m^3/ha (39.69%), and yield increased by 5.86% for M2 treatment. The highest water use efficiency was recorded for M2 treatment at (1.032 kg/m^3), while the lowest was recorded for M1 treatment at (0.588 kg/m^3).

Therefore, it can be concluded that transplanting rice using strips of furrows 80 cm in the second method (M2) is potentially high for water-saving as approximately 40% was saved, with a 6% increase in grain yield/ha in addition to a 75% increase in water use efficiency. This innovative method was conducted in 2002 on a small research area as experimental work. After that, between 2003-2005, the Ministry of Water Resources and Irrigation co-operated with Water Management Research Institute and extended it in different governorates covering all climate and soil conditions in Egypt.

3.4.2 Save Irrigation Water Using the Innovative Machine of Soil and Water Management for Rice Crop Cultivation (SWMR)

Submitted By: Dr. Mohamed El-Hagarey (2016)

The rice crop is considered one of Egypt's most important foods and export crops. In the last decade, the annual cultivated area increased from 1.08 to 1.56 million feddans, and the grain yield increased from 3.24 to 5.80 MT. The average grain productivity was 3.42 tons/fed. In Egypt, most riverine communities and farmers use a large quantity of irrigation water in paddy cultivation, creating issues like poor drainage, poor ventilation, and eventually reducing productivity and crop quality. Droughts further exacerbate the situation.

In the presented “Save Irrigation Water Using the Innovative Machine of Soil and Water Management for Rice Crop Cultivation (SWMR)” technique, rice is cultivated in tapes and strips, which saves a lot of water and reduces the used land area (Top of furrow 45 cm and 35 cm of the bottom). In the conventional technique, the rice intensity is two plants per 80 cm crosswise, while in this innovative method, there are four plants in 80 cm crosswise, meaning double the yield.

SWMR saves water, nutrients, time, efforts, applied energy, and operating costs, and the ratio of weeds growing also reduces. The new technique needs an innovative machine to manage soil for 20 cm depth. It is designed and manufactured suiting the hard environment conditions like water, heavy and compacted soil. The machine comprises a cylinder rule having many circular protrusions around the cylinder roll and a subsoil chisel of 25 cm depth behind the tractor. A design is formed on the soil of the cross-section of trenches that faces the transplanted rice rows, and the machine moves on the axe by suitable ball bearings connected to a frame having three kink points to the tractor. Section of trench width (20 cm) of the furrow edge space and reformation of the soil surface to furrows having the (V) shape is created beside the modification of trans planter float by installing the modified wheels to be suitable to the furrow shape.

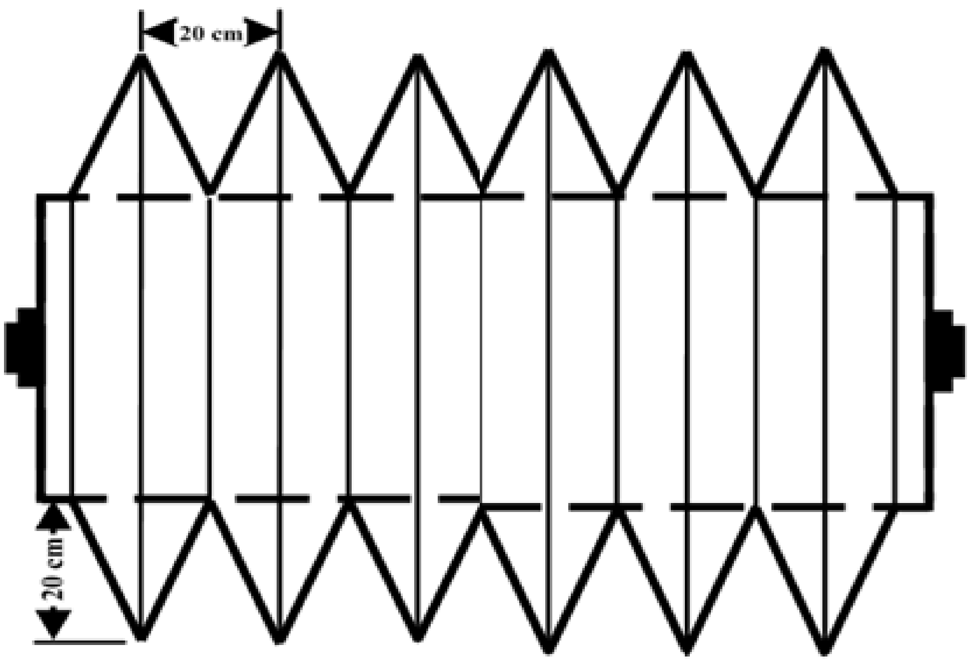

Figure 3.10 SWMR Machine

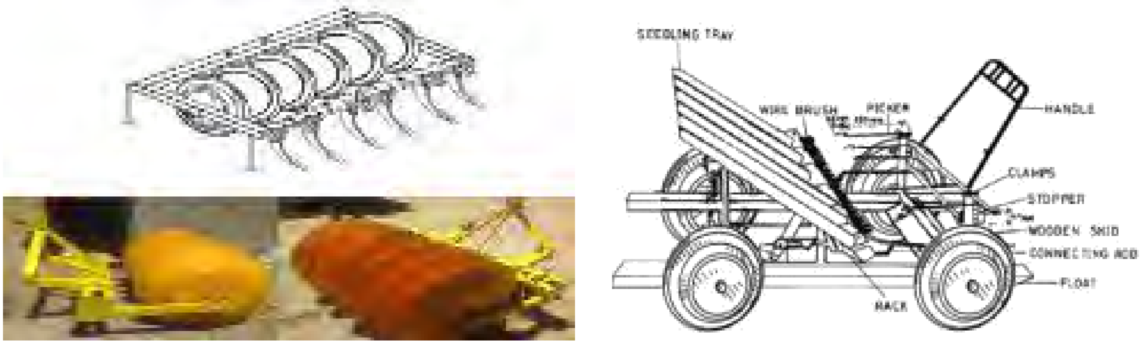

Figure 3.11A. Side view of the zigzag shape reformation and B. Subsoil chisel

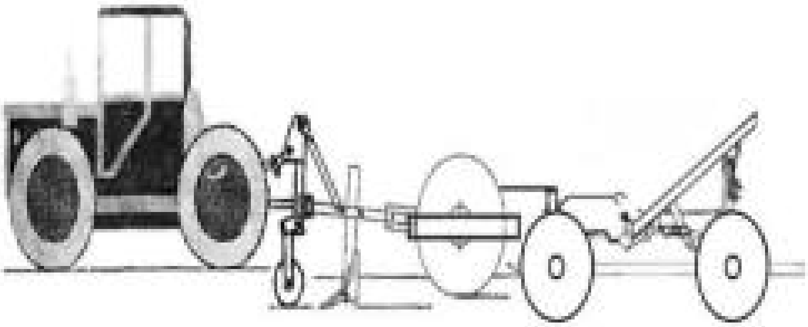

Figure 3.12 Modified wheel of modified trans planter takes the cross-soil furrow shape

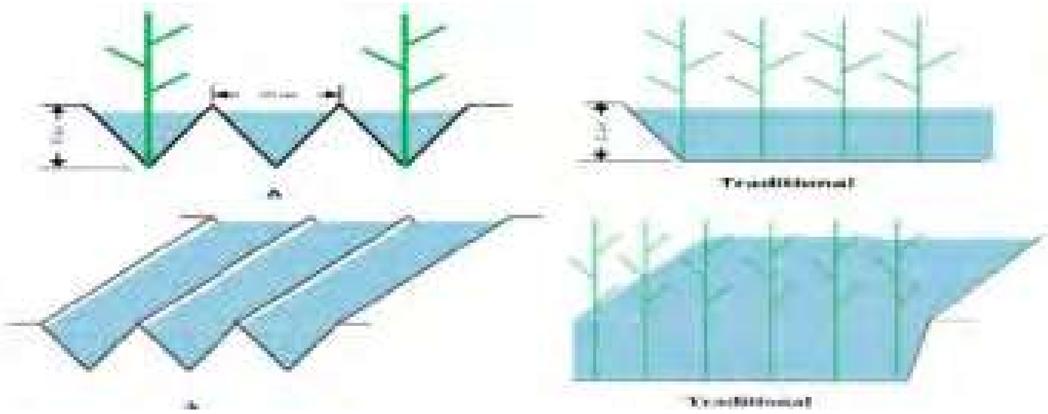

Figure 3.13 Cross-section (water flow area) of traditional and modified rice furrow irrigation.

The technique proposes transplanting rice in the bottom of the long trench of V shape, which requires almost 50% less irrigated water than the conventional method.

To assess the benefits, rice was cultivated under both conventional/traditional (WT) and innovative techniques (Wm) using the machine to prepare the soil bed. The rice intensification was kept the same under two methods. The rice was transplanted at 20x20 cm. The irrigation water requirements were estimated using local climatic data. It was found that the amounts of applied irrigation water were 13,104 and 6,897 m^3/ha for the traditional and modified method of rice cultivation, respectively, and about 47% (6 BCM) of irrigation water was saved. The rice crop yield of one hectare was 8,580 and 8,978.4 kg/ha for WT and Wm. The irrigation water use efficiency was 0.65 and 1.3 kg/m^3 for WT and Wm, respectively. Using this innovative technique and Water-Saving led to increased crop yield, nutrients saving, and reduced evaporation water losses. The traditional method was prone to mosquito and weed growth which was prevented under the new technique.

3.4.3 Application of Intensive Rice Cultivation Experience (SRI)

Submitted by: Abdul Atty Mosa Basal (2017)

Freshwater resources are in short supply to meet the needs of the growing population in Egypt. This calls for a strategic plan to maximize the use of water resources to face water scarcity. An effective management action plan was evolved by applying field research to overcome food and water security. Hence, the idea of applying rice crop intensification in a field experiment system (System of Rice Intensification - SRI) was carried out between 2014 to 2016.

The SRI system was developed in transplanting rice crops, leading to a significant increase in rice yield. The field experiment followed the research extension programme of the institute (IRRI), where some factors and coefficients were considered. The system of rice transplanting and innovation of agricultural factors led to a change in rice growth and production morphology. The implementation of the (SRI) field experiment was conducted under the supervision of and cooperation of professors from the University of *Zagzig, Egypt.* Following are the implementation details and findings:

Using the proposed system, a water-saving of about 25% down to 5000 m^3/fed against a 6350 m3/fed normal water use was witnessed. The productivity increased from 3 to 5 ton/fed to 5.5 to 6 ton/fed using about 25% organic fertiliser. The experiment was conducted in *Kafr Nekla town, Mahmoudiya Markaz, Behira* Governorate. The area was provided with pipe drainage. The soil of the area is characterized by clay type. Seedlings from the nursery were planted in three different treatments. Every treatment is applied in an area of one *kirat* (175 m^2).

The first treatment was planted with one (gesture) in a unit, at a distance of 25 × 25 cm, in the second treatment, two gestures were planted in the hole at a distance (20 × 10 cm). In the third treatment 5-7 gestures were planted randomly. Fertilizers and all agricultural treatments were applied the same. At harvest time (1m×1m) square from the three treatments, the crop production was collected for yield comparison.

As a result of the prevailing water scarcity situation in Egypt, the Ministry of Water Resources and Irrigation managed to implement a successful rice cultivation experiment with the "condensation" system in the *El-Beheira* Governorate, raising the productivity from 3.5 to 6.5 tons.

3.4.4 Using Modelling to Make Farmer Surface Irrigation More Precise

Submitted By: Samiha Ouda (2016)

About 80% of the cultivated land in Egypt is supplied with surface irrigation leading to a situation of water scarcity. The increasing population and climate change have necessitated the extensive implementation of water use optimization technique.

A water scheduling model using EXCEL was developed and named “Irrigation Scheduling Calculator, ISC”. The model required daily weather data inputs to calculate daily evapotranspiration (ET_O) using Penman-Monteith equation. The model also required the input of available soil moisture, root depth, and crop specifications. The model calculated daily water depletion from the root zone by subtracting ET_O from available soil moisture. When soil moisture reached 10.0 mm, the model determined when to irrigate and how much water should be applied. The charge from the irrigation pump was used to calculate the number of hours required to run the pump to deliver the needed amount of water.

For curtailing the inputs according to the model requirements, the farmers provided first irrigation as per traditional practices. Starting from the second irrigation, the model scheduled the irrigation. The extension worker input, the value of applied water was put in the model to calculate the depletion of the applied water from the root zone area by subtracting the value of ET_O because, at that time, no or low ground cover exists. When the model showed that there is only 10 mm in the root zone, it was time to apply the second irrigation. To determine the amount of the second irrigation, the model multiplied the value of available soil water by root depth (provided in the model's database). This amount represented the amount needed to fill the root zone with water for optimum plant growth without any water stress. Furthermore, the extension workers converted the amount of water to hours according to the discharge of the irrigation pump. This procedure continued until the last irrigation before harvest.

The model was tested by using it to develop irrigation schedules for wheat and maize planted in the *El-Sharkia* governorate. The developed schedules were compared to the actual schedules for both crops. The results indicated that the calculated applied irrigation amount by ISC model for wheat and maize was lower than the actual schedule by 6.0 and 79.0 mm, respectively. The crop productivity of wheat increased by 2% whereas there was no change in the case of maize. The water saved was around 237 m^3/ha, compared to farmer practice and the yield was almost the same. The model was partially tested in the field of one farmer in

El-Minia governorate for the wheat crop grown in the 2016-17 growing season. It was used to schedule irrigation cycles four and five.

Water scarcity in Egypt is causing the government and the farmers to work together to reduce the quantity of irrigation water. The model can be applied to many fields and vegetable crops after minor modification. The development of the irrigation schedule preparation has been tested and compared and the results are encouraging.

3.4.5 Low-Cost in-stream Wetland Treatment Technology in Egyptian Rural Areas

Submitted by: Ashraf El Sayed Mohamed (year)

Egypt is extensively working to reuse drainage water in the face of increasing population coupled with increased agricultural production. A major concern when considering drainage water reuse is water quality. About 12 BCM of surplus irrigation water is collected in drains each year, but only an approximate 5 BCM is currently being reused.

The sanitation facilities of Egyptian rural areas are far behind concerning potable water supply. Economics of scale makes conventional wastewater treatment cost prohibitive in smaller more dispersed rural settlements. Domestic wastewater is typically discharged directly or indirectly to drainage canals. This practice has contributed to the widespread degradation of drainage water quality and, so, the reuse of drainage water in Egypt has become a necessity. The introduction of passive wetland treatment systems on existing drains is an effective, cheap, and simple alternative to improving drainage water quality. A research study was conducted to verify the design criteria and demonstrate the effectiveness of the passive wetland treatment system under Egyptian conditions. Implementation of such a program involved selecting the pilot area site, conducting baseline studies, designing and constructing the wetland treatment scheme, and carrying out an environmental management plan for the scheme operation. The site selection process, major findings concluded from the baseline studies, and the potential of having a successful wetland treatment scheme is presented.

Instream wetland treatment is a promising low-cost wastewater treatment alternative that can protect drainage water from pollution. In-steam treatment technology can be implemented in drains receiving domestic wastes near neighbouring villages with certain conditions. The system is proven to be effective, feasible, and requires low operation/maintenance cost as no added chemicals are required. This technique is expected to be a promising treatment alternative to improve drainage water quality at tertiary and branch drain levels.

The following figure illustrates a typical in-stream wetland treatment system which consists of the following elements:

- (a) Sedimentation zone to reduce suspended matter and organic matter load.
- (b) Two aquatic plant zones to enhance biological treatment process.
- (c) Number of submerged berms to manage the detention time required for treatment.
- (d) Floating vegetation barriers (two to three) to avoid weed and vegetation spreading.
- (e) Control weir to manage the treated effluent discharge and detention time.

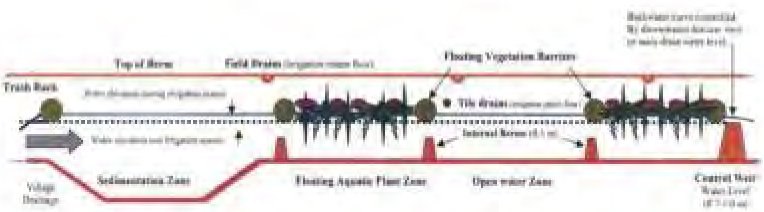

Figure 3.14 Main elements of an in-stream wetland treatment system

Pilot studies in the Nile Delta drain system were conducted to demonstrate the technical feasibility of the system and the adoption design criteria suited for the Egyptian environment. A demonstration of such technology was initially introduced in *Al Bahow* village, *Dakahliya* in the East of the Nile Delta by the Drainage Research Institute (DRI) of National Water Research Center, (NWRC) in 2006. About 300 m^3/day wastewater of small villages was treated through the drain path saving about 2 MCM/year of clean drainage water for irrigation purposes. Based on gained results, another project was introduced near *Edfina* city, in the West of the Nile Delta, in cooperation between DRI, the Egyptian Public Authority of Drainage Project, (EPADP), Abo Qir Company for Fertilizers and Chemical Products, and local city stakeholders in 2009. About 500 m^3/day of raw municipal wastewater was treated after dumping into a small drain connected to a larger suitable water quality drain (6 MCM/year).

At the pilot stage, the technology was tested in two drains, namely *Al-Bahwo* drain in-stream wetland and *Bahr Hadous* drain. Both the drains are fully operational. The treated drainage water of *Al Bahwo* drain is being reused locally and discharged into a higher scale drain that ended *at Bahr Hadous* drain and part of the treated water of *Al Bahwo* drain is being reused locally for irrigating of landscape and the rest is discharged into a larger drain used for drainage water reuse projects. After having successful two in-stream wetland pilot areas, the Government of Egypt and Holding Company for Water and Wastewater introduced more in-stream wetland in the Nile Delta which receives untreated municipal wastewater sewerage. The in-stream wetland treatment system can be applied in many other drains that can treat polluted drainage water at tertiary and branch drain levels in the Nile Delta. The treated drainage water can reach up to 2.0 BCM yearly.

In May 2015, the design of the in-stream wetland was completed, and it was further proposed to be constructed in the Nile Delta's drains, namely, *Sharaf* drain (52 MCM/year) and *Bably* drain (16 MCM/year) in the West Nile Delta and *Nishil* drain (14 MCM/year) in the Middle Nile Delta.

3.4.6 Operational Performances and New Water Control Innovation Technologies in W10 Command Areas-Egypt

Submitted By: Dr. Gamal El-Kassar (2009)

Increasing water productivity at all levels has the highest priority, water-saving and water use efficiency in crop production can be improved by optimising all operational inputs simultaneously. On these lines, new techniques were developed. This innovation covers a Monitoring and Evaluation study that was organised focusing on the application and operation of these techniques in W10 command areas in Egypt. The results were also compared to previous studies to study the impact.

The three categories of innovation were as follows:

(a) **At branch canals level:** The operation mode of secondary level distribution canals was changed from rotational (five days on and five days off during the summer) to continuous flow- water flowing continuously in the secondary canals. The downstream control gates were replaced by sluice gates provided with an automation system. Ultra-sonic discharge flow measurement facilities were also established at the branch canals and main cross regulators at the main canals.

(b) **At the *Meska* (secondary) level:** A single lifting point, the low laying tertiary water systems were replaced by pressurized/elevated system. Water was lifted from the secondary canal into the tertiary network through a single point lifter rather than the old system that allowed the farmers to lift the water through several formal/informal control points without adequate control measures, thus leading to tremendous inequity in water distribution among upstream and tail end users.

- Most of these design elements were changed.
- Reducing water duty from 1.15 l/s/fed to 0.84 l/s/fed, and increasing the velocity to 1.5 m/sec, and reducing the pipe diameter
- Increasing pump operations from 16 to 20 hours/day
- Energy source changed from diesel to electricity
- Reducing pump capacities (pumps with capacities 20, 30, 40, and 60 l/s were used).
- Changing the design of the pump house.
- Increasing the height of the water tank
- New valve types (butterfly and ball valves) were used.

Direct discharge to the pipes was investigated in a small area. On-farm level: Piping of tertiary level canals, earthen open tertiary canals were converted into piped ones, thus allowing for water delivery under pressure, reducing seepage losses, and preventing discharge of sewage into the system. *Marwas* were replaced with pipeline improved ones.

This innovation criterion was operated in an area of 6,500 fed. These implemented tools were both physical and institutional tools, including automation of discharge and regulators (branch canal level), Single point lifting (Meska Level); Forming organisations at each operational level, Branch canal level, Meska Level, and the Tertiary level (Valve group).

By reducing and controlling water deliveries to branch canals and pumping water to *meska* (secondary) and *merwah* (tertiary) levels, 15% water-saving was achieved due to changes in water deliveries. It also ensured equitable distribution between head and tail end users. It was proposed to test and implement these innovations and design criteria in the Integrated Irrigation Improved Management Project in the old land of Egypt in an area of 500,000 fed.

3.5 FRANCE

3.5.1 Aqualone, Climate Sensitive Irrigation Controller

Submitted by: Mr. Bernard Balet (2018)

Aqualone is a low-tech irrigation controller made of a clay pot, a hydraulic valve, a magnet, a float, and a UV-proof plastic holder. The valve stays off as long as the plants don't need water. It is made of simple, solid materials and doesn't require electricity, battery, or programming, but only pressurised water.

The controller responds to climate conditions, and the key trigger is the clay pot acting as a sensor and mimicking the soil's behaviour. If the weather is dry, hot, and windy, watering will happen several times a day. If it's overcast and cool, there will be a watering cycle every 2 or 3 days or less, and during rains, no watering at all. The clay pot commands the hydraulic valve closing/opening via a magnet fixed to a float placed in the plastic holder compartment. When a watering cycle is ongoing, the system gets watered the same way as the plants. The irrigation water dampens the clay pot, passes through it and fills up the float compartment. When there's enough water to lift the float, the magnet disconnects from the valve and closes it, stopping the watering. The next watering cycle occurs when the water present in the compartment is absorbed by the clay pot and evaporated.

A tremendous quantity of water was saved as only the requisite water amount is distributed with this technology. The scientific assessments carried showed encouraging results: for instance, in a comparative study on two citrus lines at the IAC (Caledonian Institute of Agronomy), not only did Aqualone use 35% less water than the electronic programmer, but it also maintained the plants in a better hydric comfort zone and delivered more homogenous irrigation. Another comparative study, performed in the park and gardens of the city of *Noumea* supervised by the IAC, led to an average of 72% water-saving on the test plots managed by the innovative technology compared to those controlled by electronic programmers and solenoid valves. Aqualone not only saves water, but it also helps in saving a significant amount of money, as it doesn't require any tricky maintenance (just rinse off the various parts several times a year depending on water quality). It neither breaks down, unlike solenoid valves.

The low-tech irrigation controller is now in a commercial development phase. There are partnerships with Gardena and Plasson to build and implement efficient water management product lines with extended partnerships to Australia. Aqualone has been selected to be implemented in Asia-Pacific. As part of a sustainable agriculture model, it will be installed in *Vanuatu, Papua New Guinea, Solomon Islands* farms. Several other partnerships with agricultural development NGOs will be organised. GK Enchanted Farm sites in the Philippines also installed the controller. Other means of further propagation of technology are as follows: Creation of reference sources with InVivo group, INRA (French national institute of agronomic research), Montpellier Sup Agro (national institute of further education in agricultural science), Dumbea golf course in New Caledonia, City of Noumea, Pernod Ricard group.

In the medium term, opportunities to partner with companies like Toro, Jain Irrigation, Insentek, Bermad are being assessed. In line with its prime purpose to allow family farms to save water with a financially and technically accessible system, it will be opened for sponsorship and patronage programmes.

3.6 HUNGARY

3.6.1 Water Retainer – Organic Soil Conditioning Product

Submitted by: Mr.Richárd Vattay and Mr. Antal Vattay (2017)

Water and Soil Water Retainer is an organic soil-conditioning product. Generally, its effects last for about three months, during which period the soil's water retaining ability is substantially increased. Applying this in the developmental stage of our plants shows benefits for root development, and better hydration lasts for the whole cultivation period.

The Retainer can be applied by either spraying on the surface or dissolved in the irrigation water (with different dilution levels possible). With time, the water retainer gets attached to both the plant's roots and the soil particles. This facilitates water applied by rain or irrigation entering the soil to trickle down to the water table, increasing the water reserve. The Water retainer springs into action when water vapour moves upwards through the capillaries; these water vapours are converted and transformed into tiny droplets of water. Usually this vapour/humidity is lost as water evaporation. These droplets can be drawn upon by the plant roots to absorb water. Meanwhile, the product also traps air humidity as an additional water supply to the soil. Water Retainer reduces the evaporation loss of the soils. This loss can exceed 40% of the total water applied. This innovation regulates water in the soil under rain-fed conditions as well.

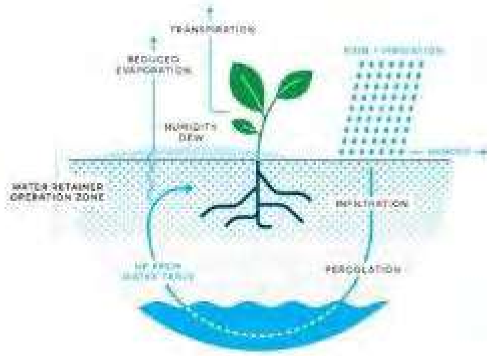

Figure 3.15 Water Retainer process

The Retainer saves up to 50% of irrigation water. This works with drip irrigation and part of the evaporation loss is saved. The application can be used either by halving water usage at every irrigation session or increasing intervals between sessions depending on the state of the plants or weather conditions.

The product substantially lowers drought damages. The plants can survive up to twice the time in drought conditions without severe damage, alleviating yield losses, while the lower stress level shows itself in better yield results. The Water retainer also reduces changes to soil conditions caused by drought, with numerous detrimental effects. Dried out soil might turn water repellent, reducing water uptake from rainfall, which in turn increases the chance of soil panning and makes it airless, resulting in less utilizable water for plants, causing an overall yield loss. The better soil humidity results in more intensive microbiological soil life, resulting in less soil degradation. The yield of various crops compared to normal application vis a vis application of soil water retainer can be appreciated from the following diagram.

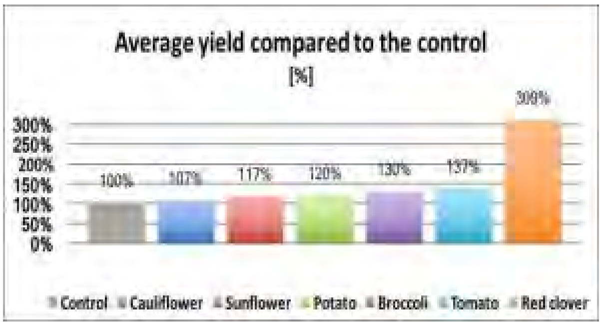

Figure 3.16 Average yield from application of soil water retainer

With the beginning of field trials in 2013-14, the administrative procedure of registration and commercial production started on a large scale in 2016. The distributorships were appointed in Morocco, Kenya, United Kingdom, Slovenia, Italy, Iran, USA, Pakistan, Greece, Spain, Turkey, and Jordan.

3.7 INDIA

3.7.1 Micro-Irrigation with Fertigation

Submitted by: Mr. Mekala Siva Shankar Reddy (2020)

Farmers in the drought-prone region of *Andhra Pradesh*, a South-Eastern state in India, cultivated various crops using innovative techniques that evolved since 1989. By constructing a water storage tank integrated with drip irrigation, they diversified their orchards from groundnuts to grapes and sweet oranges. As a result, the farming land expanded from 5 to 125 acres, which became a model farm for crop demonstration under micro-irrigation, achieving optimum utilization of the available water resources.

Despite adverse weather conditions in the arid region, farmers were able to harvest healthy crops through water-conserving irrigation practices, like drip and micro-sprinklers, and using organic inputs by adopting drip irrigation with mulching. Varieties of crops like grape (red and green), fig, hybrid papaya, pomegranate, hybrid muskmelon, pink guava, chia, and quinoa were cultivated. This was a first of its kinds experiment where drip irrigation with poly-mulch was used to cultivate muskmelon and chia in the region. There was a 51% increase in water-saving over surface irrigation. The increase in production and productivity of crops also helped in doubling the farmers' income. The drip installation reduced power consumption by 50% due to the saved number of pumping hours per day, roughly around 3.5 hours. In addition, the use of water-soluble fertilizers reduced the consumption of fertilizers by 20% using the drip system.

Considering its success, several campaigns were organized to spread awareness about the technique, such as mobile van campaigns, exposure visits to other farms, field-level training, door to door distribution of literature for the farmers, and short films showcasing success stories to mobilize the traditional farmers to adapt to micro-irrigation with fertigation continuously. Micro-Irrigation with fertigation implemented in fields increased the yield and reduced the water consumption and the use of fertilizers. Due to declining groundwater tables and the proven economic success of the technique, other farmers were encouraged to use this technique.

3.7.2 Micro-irrigation – A Technology for Prosperity

Submitted by: Dr. Yella Reddy, Mr. Satyanarayana and Mrs. G Andal (2008)

Andhra Pradesh is one of the important agricultural states with the fifth largest population in India, with over 70% of them dependent on agriculture. The total dependable flows of water from all important rivers flowing through the state was 74.14 BCM in 2002. More than 82% of water resources were used for agriculture purposes. Realizing the gravity of the situation, the government launched the Andhra Pradesh Micro-irrigation Project (APMIP), a unique, comprehensive micro-irrigation project in the year 2002.

The Micro-irrigation (MI) systems designed and installed in the farmer's fields comprised of drip systems for wide-spaced orchards, in-line drip systems for row crops, portable sprinklers, and rain guns for field crops like groundnut, pulses, etc., micro-sprinklers for raising nurseries, and micro-jets for oil palm. Agri extension services were also organised for two years. It was a revolutionary project for its time when micro-irrigation in India was emerging and yielded good results. The project details are provided below:

Implementing agencies were set up at the state level and district level for the implementation of the project. A technical committee headed by experts examined all issues. A state-level senior official headed the project as a Project Officer supported by five senior officers of different disciplines. The district-level team is comprised of administrators, experts, and farmers.

Independent quality control and monitoring and evaluation were done by external agencies. However, the farmers were having trouble in operating due to equipment design and operation constraints, which were tackled by replacing them with a low-cost hydraulically efficient semi-permanent sprinkler system to overcome the disadvantages of the conventional portable sprinkler systems.

In sprinkler irrigation, generally, 2 cm depth of water is applied in each irrigation based on the soil type, type of crop, and crop stages. Each sprinkler head covers a 144 m^2 area with a spacing of 12 x 12 m. A sprinkler head with a rated discharge of 0.5 lps needs to run for 96 mins to supply a 2 cm depth of water. Hence in a day of 7 hours power supply, a total of four shifts can be run with a total running time of 6 hours and 24 minutes. There is no loss of shift time, and the entire duration of power availability can be effectively utilized.

Major lift projects were originally designed for surface irrigation to provide water for 4,000 ha/1 TMC (27 MCM). Now by micro-irrigation, the provision was revised to 6,000 ha per 1 TMC, indicating an increase of 50%. This helped in irrigating tail-end areas in canal commands under lift projects. Semi-permanent sprinkler systems eliminated water ponding near the pipe joints and improved the working atmosphere.

The following results were obtained:

- Water-saving: 1,880 MCM (@5,000 m^3/ha),
- Energy-saving: 188 million units (@500 units per ha),
- Employment generation: Over 4,000 professionals were employed by APMIP and MI companies,
- Prevention of migration: Labour migration was reduced substantially due to more crop activity,
- Poverty alleviation and Improved quality of life.

Over 0.376 Mha under micro-irrigation with 0.236 Mha under drip systems and 0.140 Mha of sprinkler systems was achieved in four years. With further expansion, over 6,000 Mha area was covered with semi-permanent sprinkler systems. By 2008, more than 376,000 ha area was covered with MI systems benefiting over 250,000 farmers.

3.7.3 Successful Cultivation of Banana by Drip Irrigation and Tissue Culture Technology

Submitted By: Mr. Dhirendra Kumar Desai (2019)

Banana farming requires a high amount of water as the surface area for transpiration (leaf size) is quite large. About 99% of the water absorbed by the roots is transpired through stomata on leaves and regular irrigation is applied to compensate for the surface evaporation. Therefore, evapotranspiration leads to a huge loss of water in this crop under flood irrigation. Secondly, normal banana varieties grown from suckers take 15-16 months to mature for harvest, and two crops can take 28-30 months.

To cut down both the irrigation water requirement and the harvest period, a new tissue culture technology under drip irrigation was adopted, which takes ten months to harvest and allows for three crop cycle harvests in 27 months with an assured crop yield increase.

On a selected variety of bananas, tissue culture with drip irrigation and regular fertigation was applied along with a drip irrigation system. Fertilizers were applied through the ventury of the drip system. Typically, 1400 mm water/acre is required for 15 months crops in flood irrigation, whereas only 900 mm water/acre was used in the drip system.

In traditional flood irrigation systems, the water use efficiency was 35-40%, which increased up to 95% under drip irrigation, saved about 35% of the irrigation water, and reduced fertilizer requirements by about 40%. It helped reduce costs, and the technology is environmentally friendly.

In the first year, the main crop harvest was 32-35 tons/acre, while in subsequent second and third years, it was 25 tons and 20 tons, respectively. The banana yield was highest in the shortest period as 80 ton/acre was the total harvest in 27 months, thus increasing the profitability.

Given the success, the technology was adopted by several other farmers. It was adopted in many Indian states like *Maharashtra, Madhya Pradesh,* and different districts of *Gujarat* like *Vadodara, Bharuch, Chhotaudepur*, and *Anand*. With this innovative technology, cooperative societies and farmers achieved remunerative prices locally and produced high-quality export bananas. Farmers improved their economic condition and living standards and, at the same time, protected the environment.

3.7.4 Subsurface Drip Irrigation – An Innovative Water-Saving Technology in Sugarcane

Submitted by: R. Mahesh (2016)

In India, sugarcane has a high irrigation water requirement (with an average of 20 ML/ha) crop, and 80% of its water requirement is met through groundwater. Under the depleting groundwater scenario, the productivity of high-water requiring crops like sugarcane can only be sustained using technologies that economize water use. Subsurface drip irrigation (SSDI) is one of the most advanced water-saving technologies in sugarcane cultivation. It is an efficient technique to apply the requisite water quantity below the surface soil directly to the active root zone of the crop to conserve water by reducing invalid evaporation. It minimizes runoff and improves water-saving, water use efficiency, and water productivity.

Figure 3.17 Sub-surface drip irrigation and its design detail

SSDI offers many advantages over surface drip irrigation such as more accurate, frequent, and uniform water application, reduced evaporation loss, precise placement and management of water, nutrient and pesticides leading to more efficient water use, greater water application uniformity, enhanced plant growth, higher crop yield, and increased profit. If properly maintained, SSDI has a life expectancy of ten years- a cost-effective choice. SSDI also has environmental benefits; it eliminates nutrient leaching, soil erosion, and surface and groundwater sources pollution.

Among the different irrigation methods, SSDI is more efficient than surface drip irrigation (SDI) and surface irrigation (SI). Since the drip lines are usually installed in the soil between every other crop row, the system only wets a fraction of the soil volume (within the cropped area), compared with other systems. This leaves space in the soil to store water from rainfall and may reduce the net irrigation requirements.

Field experiments over three years in *Tamil Nadu*, India established that the water use efficiency improves in sugarcane cultivation under SSDI. The experiment comprised of providing filtered water to the experimental field. The water distribution/ application was controlled through valves. Experiments were conducted on two experimental fields using SDI and SSDI techniques to understand the difference between water use and water productivity. The inline drip laterals of 16 mm OD size LLDPE with emitters spacing at 40 cm apart with 4 l/h discharge rate were laid out at 165 cm. One inline drip lateral was placed for two rows of sugarcane for both SSDI and SDI treatments. Under SDI, the laterals were placed at the soil surface. Whereas in SSDI, the laterals were placed at 20 cm depth from the soil surface in the centre of every subsurface of the trench. In each of the treatments, five sugarcane rows at 165 cm and 13.3 m length were grown. The operating pressure of 1.5 kg/cm^2 was maintained at the head unit and 1.0 kg/cm^2 at the end of laterals. After installation, a trial run was conducted to assess the system's mean emitter discharge and uniformity coefficient (95%). A separate outlet with a control valve (2-inch) was given for surface irrigation.

The experimental field was irrigated up to saturated condition through SSDI and SDI system before planting. After planting, irrigation through SSDI and SDI was given uniformly for better crop establishment. SSDI and SDI were scheduled once in two days based on the 100% crop evapotranspiration (ET_C). After subtracting the effective rainfall from the crop evapotranspiration, the irrigation water was supplied. The calculated quantity of water was applied once in two days through SSDI and SDI, and drip irrigation was regulated using water meters.

Figure 3.18 SSDI stages in the field

The results from the investigation indicated that sugarcane yield (193.94 and 177.44 ton/ha in first and second crop, respectively) was significantly higher under SSDI compared to SDI (175.14 and 160.56 ton/ha in first and second crop, respectively) and surface irrigation (98.38 and 93.57 ton/ha in first and second crop, respectively). SSDI has increased cane yield to the tune of 10.51 to 10.73% over SDI. While comparing surface irrigation, drip irrigation methods viz., SSDI has produced a higher yield of 89.63 to 97.13% and SDI registered to the tune of 71.59 to 78.02% over surface irrigation.

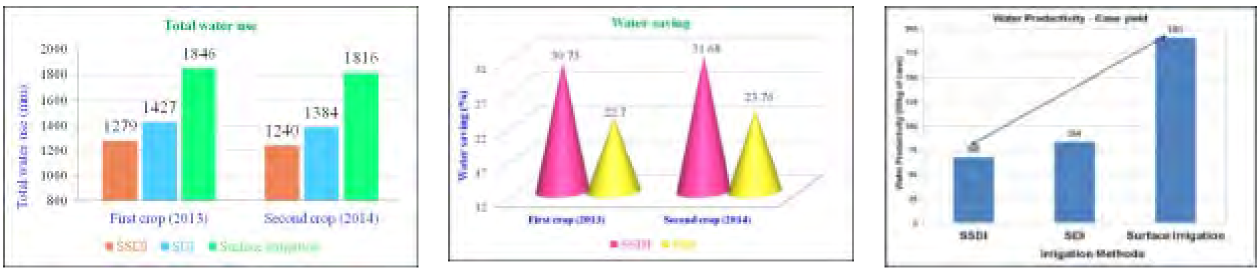

Figure 3.19 Improved water-saving and productivity with SSDI

The study indicated that the net irrigation needs could be reduced by around 30% with SSDI while maintaining higher cane productivity. Therefore, the actual water savings that can be achieved with SSDI depend on the irrigation efficiency of the system with which SSDI is being compared. A difference of about 700 mm can be saved at the farm level by using SSDI instead of surface irrigation. Still, pumping was reduced by 700 mm, and approximately one-third of the pumping cost was saved from the farmers' point of view.

Total water requirement under SSDI was only 1,279 and 1,240 mm, resulting in water-saving of 30.73 and 31.68% compared to surface irrigation (1846 and 1816 mm) in the first and second crop. Similarly, the water requirement under SDI was also lower with water requirements of 1,427 and 1,384 mm thus resulting in a water-saving to the tune of 22.70 and 23.76% compared to surface irrigation (1846 and 1816 mm) in the first and second crop. Among SSDI and SDI methods, SSDI has achieved an additional water-saving of 8-9% (148 and 144 mm) compared to SDI in the first and second crop, respectively. The quantity of water required to produce 1 kg of sugarcane under SSDI was only 68 compared to SDI with 84 l. In the case of surface irrigation, it was around 191 l which was low water productivity. Hence under SSDI, the water productivity was 2.7 times higher and 2.2 times higher under SDI than surface irrigation.

SSDI was promoted among sugarcane growers through various extension activities, including meetings, training, field demonstrations, and expositions. This extension work was aimed to convince the farmers and build their capacity for using SSDI. Subsurface drip technology was adopted rapidly between 2009 and 2012). By applying this technology all over India for sugarcane cultivation, a total of 37.17 BCM of irrigation water can be saved.

3.7.5 Innovation for Making Potable Water Available in Saline Groundwater Areas

Submitted By: Lalit Mohan Sharma (year)

Groundwater is a vital component of the water resource system. Being the largest reserve of drinkable water for the human population, groundwater has always been crucial to human civilization. However, the deteriorating quality of groundwater due to increasing contamination by various toxic substances is a growing concern. Ingress of seawater, intrusion of other saline groundwater, or polluted water from the surrounding areas make it unfit for use. Depletion of groundwater changes the flow (both direction and velocity) of the groundwater, which may cause an inflow of polluted water into the freshwater aquifer from surrounding areas. In coastal areas, this results in seawater intrusion into the freshwater aquifer. The major consequences are potable water scarcity and a rise in groundwater salinity. Furthermore, the lack of regulatory policies on groundwater mining poses the risk of ingesting toxic compounds.

Saline water has a relatively high concentration of dissolved salts such as cations and anions. Besides sodium chloride, salt also has dissolved calcium, magnesium, sulphate, bicarbonate, boron, and other ions. It is assessed in terms of ‘total dissolved solids (TDS) measured in part per million (ppm) or mg/l but approximated by measuring the electrical conductivity (EC) of water, expressed in decisiemens per metre (dS/m). The palatability of water with a TDS level of less than 600 mg/l is generally considered good and significantly unpalatable at TDS levels greater than 1,000 mg/l.

To address the issue of potable water scarcity caused by salinity, an innovative model of roof water harvesting system was conceived and tested in groundwater salinity affected *Mewat* district of *Haryana*, a northern state in India. The technology was developed to address the regional constraints like high dependency on groundwater, short rainy season with a low annual average rainfall of 594 mm in 31 rainy days, shallow groundwater tables, high levels of groundwater salinity, non-availability of reliable grid electrical supply, poor household economy and low skill set of the community.

The technology aimed to recharge the groundwater with harvested rainwater. Conventional rainwater harvesting has the limitation of the construction of storage tanks. In this case, recharging was done at a depth under the ground, leaving a safe distance above the groundwater table so that the recharged water gets infiltrated into the ground to avoid contamination of groundwater. But this recharged freshwater does not remain in a consolidated mass and spreads out over some time. Eventually, the recharged freshwater forms a thin layer over the existing saline groundwater to maintain hydraulic equilibrium, as shown in Figure 3.20.

Exploiting this thin layer of fresh groundwater separately is practically difficult as it gets mixed up with the existing underlying saline groundwater in the process. A sizeable pool or pocket was created spread over a larger area to exploit the harvested rainwater separately.

To achieve this, the traditional recharging was redeveloped. Recharge wells were sunk to a depth lower than the groundwater table in the newly developed model. The desired freshwater pocket could be formed by pushing away and replacing the existing saline groundwater. The harvested freshwater from this pocket could be extracted as it was pushed by surrounding saline groundwater pressure. The groundwater table is often shallow in saline groundwater areas, often limiting the recharging rate by creating low hydrostatic pressure (overburden pressure). To overcome this challenge, the recharge well was raised to a roof height, leaving a margin to accommodate a pre-filter that removes suspended and floating materials coming with rainwater from the roof. This way, the hydrostatic pressure for recharging was increased with an additional hydrostatic head.

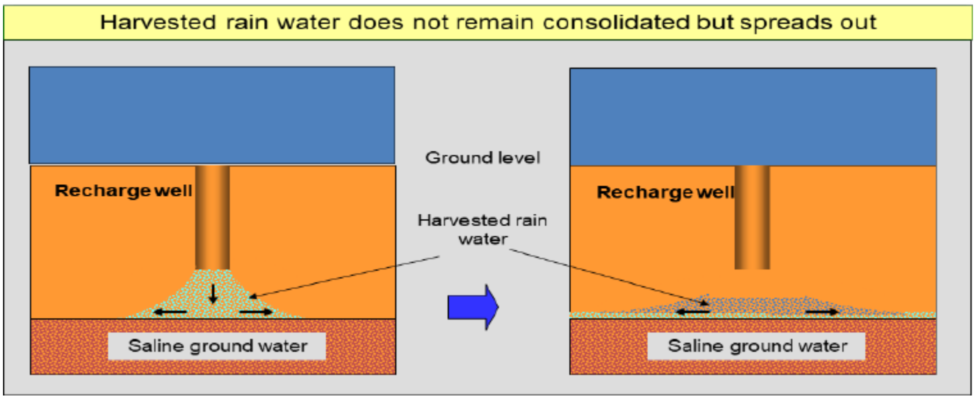

Figure 3.20 Spread of freshly harvested rainwater under the ground

The innovation contributed towards water savings in the following ways.

Annual rainfall is the original and significant source of fresh water in the region. This crucial source of freshwater was not lost or mixed with the saline groundwater areas; instead, was captured and used as potable water.

By making available a source of potable water locally, the innovation reduced the demand for freshwater transported from the already over-stressed source outside of this saline area. It also saved the distribution losses and energy and transportation costs.

In 2013, in a government school building in *Untka* village in *Mewat* district, a roof water harvesting system was established to recharge aquifer with rainwater using this innovative model. Since July 2013, the school has been using the recharged water that is made safe for drinking by filtering through a bio-sand filter. This filtration process eliminates the risk of biological contamination. The cost involved in this model's construction, operation, and maintenance is far less than alternative water treatment methods like reverse osmosis systems.

A total of 12 demonstrations of this model are installed in *Mewat (Haryana) and successfully meet the schools' potable water need*s. Another demonstration was being implemented in deeper saline aquifer conditions in *Jhunjhanu (Rajasthan).* Each demonstration annually harvests a minimum of 3,00,000 l of rainwater. Utilizing rainwater for school water needs has also resulted in cost savings in purchasing water. The beneficiary base of these demonstrations is over 4500 students, teachers, and other staff. This model is a sustainable solution for potable water availability in saline aquifers. It can be expanded by increasing the surface area of water collection through connecting rooftops of buildings. Water harvested through individual rooftops can collectively recharge rainwater in recharge wells. Locating recharge wells at suitable points in the village would ensure access to water to all the village parts.

3.7.6 Development of less Water Consuming Rice Varieties Pyari and Satyabhama

Submitted By: Dr. Sharat Kumar Pradhan (2012)

Rice is a water-intensive crop. A lot of water is being used during puddling and transplanting, and it is estimated that 3000-5000 l of water is consumed to produce one kg of rice in flooded irrigation rice. Aerobic rice is grown under moderate moisture stress (non-flooded and non-puddled) and direct-seeded conditions without sacrificing potential yield. There is a saving of 40-45% water, along with labour, nutrient, and other inputs compared to irrigated transplanted rice. Therefore, new aerobic varieties of rice were developed. *Pyari* (IET 21214), a less water-consuming rice variety, was developed and released for the aerobic and water limiting areas of *Odisha* state in India. The variety has consistently outperformed the national, regional, and qualifying check varieties under the national testing from 2008-2010. Under three years of national testing, the culture exhibited stable yield and other traits in the aerobic areas of *Chhattisgarh, Jharkhand, Tamil Nadu, Punjab,* and *Gujarat states*. It exhibited 13.18%, 17%, and 20% higher grain yield over national and regional checks pooled over three years of testing across different zones of testing in the country.

Under field testing conducted by the state department of agriculture, it exhibited a better yield in water limiting areas of the state. The maturity duration of the variety was 115-120 days, semi-dwarf, non-lodging plant type with an average of 272 panicles/m^2. It produced short, bold grain, moderate tillering (7-10), more grains/panicle, and a compact panicle with a test weight of 24 g. The line was moderately resistant to leaf blast, neck blast, brown spot, stem borer damage, whorl maggot, gall midge biotype 6, and leaf folder attack. The variety had a higher response to fertilizer application as compared to checks and qualifying varieties. The variety possessed good hulling milling, white kernel, medium slender grain, no grain chalkiness, and desirable alkali spreading value. The variety trial was conducted at *Ludhiana, Kaul, Cuttack, Ranchi, Raipur, Navagoan, Bangalore,* and *Coimbatore* locations identified as controlled sites for national testing of aerobic materials.

Satyabhama (IET 20148), a drought-tolerant rice variety, was developed and released for the drought-prone areas of *Odisha* state, India. The variety outperformed the national, regional, and qualifying check varieties under the national testing from 2006-2008 under drought stress situations. Under three years of national testing, the culture exhibited stable yield and other traits in the drought areas of *Odisha* and *Chhattisgarh* state. The variety led to a higher yield in the national, regional, and local checks by 29%, 31%, and 16%, respectively, in the drought-affected region. It produced long slender grain (6.75 mm), 250 panicles/m^2, moderate tillering (6-9), and produced long panicle (28 cm). IET 20148 possessed all desirable quality characters like high head rice (60%), intermediate alkali spreading value (7.0), intermediate amylose content (24.66%), and L/B ratio of 3.35. The line exhibited a resistance reaction against the pests' stem borer, leaf folder, and rice whorl maggot attack. It showed moderate reaction to white-backed plant hopper, gall midge biotype1, biotype 5, rice hispa, rice thrips, EHB, and GRH attack. It showed a moderate tolerance reaction to diseases like Leaf blast, rice tungro virus disease, and glume discolouration. The culture exhibited a better performance under farmers' field trials. The entries were evaluated in the drought-prone site of each location under national trial, where the genotypes face drought stress each year. The test locations were *Jagdalpur, Raipur, Rewa, Cuttack, Bhubaneswar,* and *Jayapore,* which were identified as the controlled site for drought breeding materials. The variety was found to be promising in many country zones over check varieties.

Overall, the variety *Pyari* consumed less water than conventional irrigation methods and saved around 40% water which can be used for other purposes. Similarly, *Satyabhama,* a drought-tolerant variety, required even less water than the aerobic variant. Thus, a lot of water can be saved by cultivating both varieties. These varieties can be further cultivated in drought-prone and aerobic regions in the country.

3.7.7 Micro-irrigation Technology for "More Crop Per Drop" in Tamil Nadu (India)

Submitted By: Dr. N. Asoka Raja (2013)

Efficient utilization of available water resources is crucial for a country like India, which shares 17% of the global population with 2.4% of land and 4% of the global water resources. In *Tamil Nadu*, a southern state in India, the average annual rainfall is 908.9 mm (2011) over a geographical area of 13 Mha. To meet the food security, income, and nutritional needs, Micro-irrigation was adopted. The emphasis was on water conservation and water-use efficiency to achieve "More Crop per Drop."

Micro-irrigation is promoted by state and central government through various schemes like Nation Mission on Micro-irrigation (NMMI), Tamil Nadu Horticultural Development Agency (TANHODA), Irrigated Agriculture Modernization and Water-bodies Restoration and Management (IAMWARM), Nation Agricultural Development Project (NADP), National Committee on Plastics in Agriculture and Horticulture (NCPAH) and Tamil Nadu Precision Farming Project (TNPFP). Micro-irrigation techniques were first standardized in close-spaced crops in 1998 under government schemes. Later these technologies were evaluated in several horticultural and field crops.

The standardized technology was scaled in *Tamil Nadu* through TNPFP in *Krishnagiri* and *Dharmapuri* districts, covering 400 ha in 23 crops with the government's financial support. Micro-irrigation and fertigation being the core technology of precision farming, was demonstrated in 400 ha in three years and recorded a 60% increase in yield with 90% marketable quality. The beneficiary farmers were identified in a cluster approach in the respective districts, and farmers associations were formed to implement the project in 400 ha further.

Impact of adoption of drip and fertigation technology through Precision Farming Project

The farmers reported significant labour and water savings after adopting precision farming techniques besides reduced effort applied for irrigation, weeding, and other soil preparation activities. In terms of labour savings, a single labourer, who could previously only work on 3 acres, could now work on 8 acres. In terms of water requirements, one farmer revealed that 3 acres of land could be irrigated instead of 1 acre with the same amount of water.

TNPFP farmers' yield of tomato, brinjal, banana, chilli, watermelon, muskmelon, cassava, and cabbage were at least 3 to 12 times higher than the national average. Four other crops- tomato, chillies, cabbage, and cauliflower were further cultivated in a 100-ha field in a non-project area. A cabbage farmer recorded 35 tons/acre with drip irrigation compared to 15-20 tons without drip irrigation.

Apart from yield, the quality and consistency of the product also improved. One farmer reported that the average size of cabbage produced increased from 2.5 kg to 3.5 kg with an extended shelf life of the product. Improved quality of crops led to an increase in farmers' income.

Remarkable water-saving was achieved under a drip system in water-hungry crops like sugarcane and banana. Drip irrigation was the most accepted technology by the many sugar factories in *Tamil Nadu*. Hence drip area coverage increased up to 90% of the registered cane growers. Similarly, bananas occupied the second position with large area coverage under the tissue culture banana among various crops under the drip system. The overall water-saving under the drip irrigation system increased water productivity. Thus, drip irrigation resulted in a twin benefit of water-saving (30 to 50%) and yield increase (10 to 60%) in various crops.

In *Tamil Nadu,* the adoption level of drip and sprinkler irrigation area reached 0.142 Mha against the net irrigated area of 2.9 Mha, accounting for only 5% under MIS (2013); thus, there is vast scope for further expansion.

3.7.8 BBF Planter cum Inter-Row Cultivator for In-Situ Moisture Conservation

Submitted By: Mr. Vivekkumar Prakash Khambalkar (2014)

The agricultural productivity in rain-fed farming is highly susceptible and rainfall-dependent. In rain-fed agriculture, water availability during critical crop growth stages is of paramount importance from a yield perspective. In traditional farming, most farm operations are time-consuming, and delay in sowing of crops reduces the yield. The frequent occurrence of dry spells makes repeated sowing essential, increasing the cost and reducing yield quality and quantity. The in-situ moisture conservation is the most important aspect in rain-fed farming for conserving every drop of available water. The presented innovation was developed to find the solution for in situ moisture conservation and reduce the cost of cultivation which is the prime need of rain-fed agriculture.

In this innovation, a multifunctional precision farm machine was developed for the application of inputs, that enhanced the in-situ conservation of moisture and led to smooth intercultural operations. The developed technology was called Broad Bed Furrow (BBF) planter cum Inter-row Cultivator.

The machine sows the crop in four rows and makes two furrows. The rainfall on the broad bed having depth ranges from 10 to 20 cm is conserved and the rainwater is being infiltrated into the soil bed. The excess rainwater on the bed is percolated into the furrow and later, it is infiltrated into the soil. The infiltrated rainwater increases the rainwater into the soil. Excessive water is drained out from the furrow. The conserved rainwater increases the soil moisture, especially during dry spells. Chickpea crop was sown in more than 1000-acre area using this machine during the *rabi* (winter) season in *Washim* district of *Maharashtra* state in India.

Planting mechanism and broad bed furrow formation: The developed planting machine can easily plant the crop in four rows spaced from 30 cm to 45 cm. The formed bed size is in the range of 90 cm-120 cm as per the requirement of various crops like soybean, safflower, green gram, chickpea, groundnut, and others. The planter has two ridges for making two furrows and desirable bed size. Planter forms one bed of size 90 cm -120 cm and two furrows of size range from 30 cm to 60 cm. Four furrow openers having adjustable crop row spacing are provided to plant the seed on the formed broad bed using an inclined plate mechanism.

The adoption of such precision machines in farm operation reduces the cost of operation, conserves soil moisture, and increases crop yield. The machine can do three operations simultaneously (i) broad bed and furrow formation, (ii) precision seed placement, and (iii) fertilizer application. The spacing between crop rows as well as between two subsequent seeds can be adjusted easily as per the requirement. The size of the bed and the size of the furrow can be changed as per requirement. Effective weeding and intercultural operation can be carried out with minimal soil inversion, which helps break the capillaries formed within the soil body. This reduces the loss of soil moisture in the form of evaporation.

The labour requirement for sowing by the BBF planter is from 5-6 man-hr/ha. Whereas for traditional practice, it is 33-125 man-hr/ha for different crops (Green gram, Soybean, Chickpea, and Safflower). The net savings in sowing and intercultural operations were 20-40% and 14%, respectively, for different crops. An increase in yield of crops was 9-14% due to effective in situ moisture conservation. A 2013 survey revealed that the crop yield for chickpea increased by 12-15%. It was found that 15% of the average moisture was retained in the BBF planter sown crop compared to the traditional method of sowing throughout the crop duration.

3.8 IRAN

3.8.1 Designing Micro-Lysimeter for Accurate Measurement of Crop Water Requirements

Submitted By: Mr. Mahdi Sarai Tabrizi (2017)

Water scarcity and non-accurate measurements of crop water requirements create severe problems for agricultural water management in arid and semi-arid regions. There was a need to develop low-cost equipment that works with precision, simplicity, and results in water-saving.

Based on the requirement, a drainage-weighted micro-lysimeter was designed. It was developed for simplicity and accurate measurement of crop water requirements based on the water and soil balance equation. Due consideration was given to available and relatively inexpensive equipment compared with the two common measuring methods (theta probes and pan evaporation methods. The results under indoor conditions (greenhouse), outdoor conditions (pot study), and in-field conditions were investigated. The benefits of this method in field conditions over the other two measurement methods were proven.

Micro-lysimeters used three 10-l buckets and one drainage hole. A thick domestic hose from each bucket was passed through the hole and connected to a small bucket with a lid. Then the buckets were filled with one layer of coarse sand soil 3 cm thick and were passed through a 200 mm sieve, as shown in Figure 3.21.

Figure 3.21 Construction, soil preparation, and filling stages in the proposed micro-lysimeter

After comparing the three measurement methods with each other, a pot level study was conducted in a 1-ha experimental field with irrigation management scenarios including full irrigation treatment (FI) and three deficit irrigation treatments (DI 80%, DI 60%, and DI 40%) at 100%, 80%, 60% and 40% of crop water requirement based on the percentage of mean full crop water requirement of micro-lysimeters respectively in two agronomical years 2015 and 2016. Every 12 hours (6 am and 6 pm), micro-lysimeters and the drainage water content were collected and weighed during the entire growing season. The drained water quality was measured using a portable EC meter. This method for estimating crop water requirement was done based on water and soil balance; the theta probes method was based on the soil moisture deficit compensation method, and the third method was based on measuring evaporation from class-A pan evaporation method from the local synoptic station (*Doshan Tappeh* station) (Figures 3.22).

Figure 3.22 View of the proposed micro-lysimeter, Theta probes, and U.S. class-A pan evaporation methods used in the experimental farm

In micro-lysimeter and theta probes methods, the amount of crop-absorbable moisture was calculated, and then irrigation was applied when the moisture reached that level. The depth of irrigation water was determined. The rate of maximum available depletion (MAD) was 30%. The crop water requirement was calculated using the soil and water balance equation. In class-A pan evaporation method, daily climatic data were used to calculate reference evapotranspiration (ET_O) by FAO-Penman-Monteith equation. Crop coefficient (K_C) was determined using ET_C obtained by micro-lysimeter, and ET_O obtained using FAO-P-M reference evapotranspiration.

It was found that micro-lysimeter saved about 10% of the irrigation water compared to Class A pan evaporation and Theta probe. This technique can prove to be beneficial in water-deprived areas that have limited facilities. The measurement of basil evapotranspiration showed that against a maximum of 545.8 mm with Class A pan evaporation micro-lysimeter had 490.74 mm. The corresponding average values were 545.447 and 498.317 mm, and basil yield indicated that under theta probe, the maximum yield was 65.7 g/pot, whereas, under micro-lysimeter, it went up to 71.3 g/pot. The corresponding average values are 65.07 and 68.62 g/pot. Despite the reduction in water consumption in the micro-lysimeter, crop yield was increased by about 10%. The results indicated that drainage-weighed micro-lysimeter reduced crop water requirement than evaporation pan, and the theta probes methods based on T-test and other observed data.

This experiment demonstrates four important implications for sustainable farm water use in arid and semi-arid regions. This technology is low-cost and does not require a minimum standard area. Unlike evaporation pan and theta probes methods, which require data gathering, data recording, and complex measurements, micro-lysimeter preparation is easy to learn and implement. Moreover, the accuracy of theta probes set depends on soil type and is recommended for sandy soils, but this micro-lysimeter can be used in all kinds of soil textures. The need for estimating actual crop water requirements for suitable irrigation scheduling to achieve maximum crop yield with the optimum water consumption in arid and semi-arid regions has been demonstrated using lysimeter in terms of water-saving up to 10%, increase in crop yield up to 10%, cost-effectiveness and ease of use.

3.8.2 Use of Low-Pressure Subsurface Irrigation System with Perforated PVC Pipes to Reduce Water Consumption in Pistachio Orchards

Submitted By: Dr. Nasser Sedaghati (2020)

Pistachio Research Institute, located in *Rafsanjan* city of Iran, developed an innovative irrigation technique between 2011-2014 along with a few gardeners, approved by the Institute of Technical Research and Engineering, considering its positive results.

In this technique, water from the source of irrigation water supply (well or water storage pool) is transferred to pressurized pipes up to the garden using the pumping system and then poured into the pool by special valves. The water, coming out of the pressurized state, moves by the force of gravity based on the slope of the earth inside the water pipes. Inside each pool, water pipes transport the water under the soil and around the roots of the trees. The ends of the discharge tubes are also open and are connected by a knee to a vertical tube (ventilator). This ventilator is responsible for discharging air into the pipe and facilitating water flow inside. Water pipes with different diameters (90 mm to 125 mm) are installed depending on the soil texture, length of rows, irrigation system flow, land slope on both sides of the row of trees, and at a certain depth from the soil surface (30 cm to 60 cm). The installation depth of the water pipes depends on the soil texture and is usually chosen to have the least amount of moisture on the soil surface to prevent surface water evaporation losses. If the distance between the rows of trees is less than 5 m, only one pipeline in the middle of the rows of trees is used. The distance of the pipes from the tree's trunk also depends on the texture of the soil, the age of the plant, and the dimensions of the crown of pistachio trees and usually varies between 0.8 and 1.3 m. The length of the pipelines between 30 and 100 m is usually acceptable and is considered less in light soils (maximum 70 m). The diameter and distance of the holes on the pipes also depend on the texture of the soil, the planted trees rows' length, and the amount of discharge entering each pipe. So, the diameter of the holes varies between 9 mm and 12 mm, and their distance from each other varies between 15 cm to 35 cm.

Unlike micro-irrigation systems, in this technique, the heavier the soil, the larger the diameter of the holes, and the shorter the distance between the holes. Since a large volume of water must be distributed quickly in the root zone of trees, the main holes responsible for distributing water in the soil are placed at an angle of about 45 degrees to the line perpendicular to the floor of the pipe at a certain distance. Holes are also installed on the floor of the pipe one by one between the main holes to drain the pipe water completely. The inflow of water to each pipeline depends on pipe diameter, pipeline length, and soil texture and usually varies between 2-8 l/s. Around the tubes, a layer of gravel about 10 cm thick is placed as a filter. The diameter of the filter particles is usually between 6 mm and 12 mm. The filter is used on the bottom and sides of the pipe, and there is no need for a filter on the pipe. This gravel layer prevents soil particles from entering the pipe, prevents soil leakage, creates a uniform environment for better water distribution along the pipeline, and prevents plant roots from entering the pipe. A layer of nylon on the pipes prevents soil particles from entering the filter during winter leaching.

In addition to reducing water consumption and increasing water use efficiency, the technique has three main advantages:

(a) Possibility of using it in saline waters due to its low sensitivity to clogging water outlets.
(b) Good adaptation to retail conditions due to the possibility of distributing large volumes of water in the root zone of garden trees in a short time.
(c) Possibility of reducing irrigation frequency in gardens with a high irrigation cycle.

First research work on this irrigation system resulted in a 25% reduction in water consumption (about 1,800 m^3/ha) and a 62% increase in water use efficiency compared to flood irrigation. Additionally, depending on the planting distance of trees, it is possible to reduce water consumption by 50% compared to conventional flood irrigation in pistachio trees in the region. Another important advantage of this system over micro-irrigation systems is its good adaptation to micro-property conditions and the possibility to reduce the irrigation cycle in pistachio orchards with long irrigation frequency.

In the last few years, different installation depths of the pipe, the diameter of the pipe, and the diameter and distance of the holes on the pipes have been evaluated. In addition, the effect of the design on moisture distribution, and soil salinity were evaluated more accurately. Other complementary tasks included optimizing and manufacturing a special filter for round pipes or polyethylene prefabricated pools to facilitate the implementation of this irrigation system.

3.8.3 Reduction of Water and Phosphorous Losses and Soil Erosion by Creating Micro-Dams in Furrow Irrigation

Submitted By: Mr. Mohammad Sadegh Keshavarz, And Dr. Hamed Ebrahimian (2020)

Soil erosion in Iran is very high, nearly 2.5 times more than the world average, impacting agricultural output. This peculiar problem of soil erosion requires innovative irrigation techniques. One such technique is the placement of micro-dams in furrow irrigation, which helped reduce water and phosphorous losses and increased water savings.

Despite the availability of modern irrigation methods globally, surface irrigation is still widely applied in agricultural lands, with furrow irrigation being one of the most common methods. Farmers in Iran also employed surface irrigation, reducing water flow velocity and runoff rate by placing soil or straw (as a barrier) inside irrigated furrows. However, this traditional operation has not been systematically investigated. Despite all the advantages, the open-end (free draining) furrow irrigation method has one disadvantage: when the water reaches the end of the field, it freely moves out of the field and consequently dissolves matters. The eroded sediments are transferred out of the field. Phosphorus losses occur in surface irrigated fields by soil erosion released by runoff from the field. Eventually, it reduces the quality of downstream water resources. Therefore, an appropriate technique was developed to control soil erosion and water losses.

The presented technique is the creation of micro-dams inside the irrigated furrows. It effectively reduces surface water velocity, soil erosion, and run-off and phosphorus losses from the agricultural fields. The low cost of micro-dams and the simplicity of their construction are the prime advantages of this technique. A field study observed the effects of these micro-dams. Field studies and experiments were conducted at the College of Agriculture and Natural Resources, University of *Tehran, Karaj*, Iran. The soil texture was clay loam and the farm's slope were 0.96%. Measurements were carried out in four irrigation events at the beginning of the season. This study investigated the combination of two erosive inflow discharges (0.6 and 0.9 l/s) and two micro-dam distances along the furrow (20 and 10 m). A control treatment (a furrow without micro-dams) was used for each experimental discharge. Therefore, six treatments were established.

Consequently, 24 irrigation evaluations were performed. Super Phosphate ($Ca(H_2PO_4)_2H_2O$) fertilizer was applied for providing phosphorus. The amount of pure phosphorus added to the soil was 40 kg/ha. After fertilization, experimental furrows with a length of 100 m and a spacing of 0.75 m were created by the furrower machine. The experiment required 18 contiguous furrows. Micro-dams were manually built to create a 0.05 m hump above the average local furrow base elevation.

Furthermore, the micro-dams were covered with plastic film for preventing their destruction by overflowing water. In control and treatment furrows, inflow and outflow discharges were measured using WSC Type 1 flume. The amount of erosion and phosphorus losses were determined by runoff sampling at different periods. The phosphorus concentration in the runoff water sample was measured by a spectrophotometer device.

Micro-dams substantially reduced the runoff, runoff sediments, and phosphorus losses when compared to the control treatments. The increase in discharge increased flow velocity and the furrow wetter perimeter and consequently increased runoff and sediment losses for all treatments and irrigation events. In addition, micro-dams were more effective in controlling erosion in the high inflow discharge treatments. The effectiveness of micro-dams in controlling erosion at large inflow discharges was an important finding, suggesting that this technique can be adequate for sloping areas where the soil is prone to erosion. Also, phosphorus losses were higher for higher discharge, indicating that phosphorous losses may be very sensitive to inflow discharge. Since phosphorus is attached to soil particles, an increase in soil loss causes increased phosphorus losses in runoff.

Compared to the control treatment, the following reduction in runoff, runoff sediment, and phosphorus loss was observed for micro-dams with distances of 20 m and 10 m, respectively.

(a) For micro-dam spacing – 10 m and inflow rate 0.6 l/s – Runoff decreased by 45.4% in the first irrigation event and by 32.3% on the average of the four irrigation events

(b) For micro-dam spacing – 10 m and inflow rate 0.9 l/s – Runoff decreased by 37.4% in the first irrigation event and by 24.5% on the average of the four irrigation events

(c) For micro-dam spacing – 20 m and inflow rates of 0.6 and 0.9 l/s – Runoff reduced by 26.7% and 17.9% respectively, compared to the control treatments

(d) In the absence of micro-dams, the sediment losses in the discharge of 0.9 l/s were 69% higher than in the discharge of 0.6 l/s

(e) For discharge of 0.6 l/s, reduction in runoff sediments – 25.2% (20 m distance) and 33.0% (10 m distance)

(f) For discharge of 0.9 l/s, reduction in runoff sediments – 25.3% (20 m distance) and 59.5% (10 m distance)

(g) For inflow discharges of 0.6 l/s and 0.9 l/s, micro-dams spaced 10 m significantly reduced erosion (p-value <0.05).

(h) For discharge of 0.6 l/s, reduction in phosphorus losses – 12.9% (20 m distance) and 32.2% (10 m distance)

(i) For discharge of 0.9 l/s, reduction in phosphorus losses – 24.1% (20 m distance) and 37.4% (10 m distance)

Observation: Micro-dam in the furrow stored and saved water in two ways. In the first stage, the micro-dam reduced irrigation runoff losses from the field and subsequently led to saving water. The results of this study indicated that micro-dams in furrows reduced 45.3% of total runoff from the field. Secondly, the micro-dam also provided non-direct storage of available water resources by preventing the transporting of fertilizer to downstream water resources and contaminating them, thus preserving the quality of water resources. Micro-dams in-furrow reduced soil erosion up to 59.5%, and also prevented the loss of phosphorus up to 37.4% in comparison with the control treatment.

Future studies on this topic could focus on modifying a furrowing machine for creating micro-dams to reduce labour costs, optimizing micro-dam design for different inflow discharges, soil textures, and field slopes, and establishing the economic implications of micro-dams in different open-end furrow irrigated agricultural production systems.

3.8.4 Savings in Irrigation Water by Adding Fuel from Livestock Waste to Agricultural Land

Submitted By: Mr. Amirali Fatahi1 and Ms. Fatemeh Sadat Mortazavizadeh (2018)

Traditionally, the animal waste residue has been used as a fuel in Iranian rural areas in furnaces, baking ovens, heaters to provide heat and energy. The ashes produced from the burning mainly consist of a silica compound called "*Koul*" (in local language) and has structural differences with charcoal ash. Due to limited research on the use of *koul,* an experiment was conducted to understand the various uses of this type of ash.

This project was implemented in *Ghani Beigloo* Village, *Zanjanrood Department of Zanjan*, in 3 blocks and 12 plots. The area of each plot was 2.25 m^2. The number of treatments was selected based on the most effective amount proposed in the sources.

In three types of clay-loam, sandy-loam, and clay soil texture, 3 treatments weighing 10, 20, and 30 ton/ha of ash were added to the clay-loam soil texture to test the percentage of moisture content, the average rate of water penetration in soil and basic penetration rate. At first, a soil sample was taken from a depth of 0-30 cm and soil texture was determined according to the standard hydrometric method - ASTM D422-63. Then, the percentage moisture content of each plot was calculated based on the standard moisture content determination test, AASHTO-T73-293, ASTM D2216-71, and the resulting data were analysed.

Figure 3.23 Blocks and Plots

A detailed analysis of the experiment is presented below:

Determining the percentage of moisture content

The percentage of soil moisture content was calculated to determine the exact time to irrigate plants according to the plant's water requirement. Compared to the control treatment, in clay loam soil, the water penetration rate of soil was increased in treatments of 10 and 20 ton/ha of ash but in the treatment of 30 ton/ha, the penetration decreased due to the reduction of effective porosity of the soil. In loam sandy soil, *Koul* had little effect in the treatment of 10 ton/ha and showed a decrease of penetration rate in 20 and 30 ton/ha. (Presented in Table 3.1)

Table 3.1 Percentage of moisture content according to the tests

Ash			Witness	Treatment type
ton 30	ton 20	ton 10		Soil type
7.49	8.77	8.07	6.11	Clay Loam
7.25	5.71	4.68	4.3	Sandy Loam
9.88	8.37	8.23	7.5	Clay

Different soil textures require different treatments for maximum moisture content in the depth zone of 0-30 cm. In all three treatments in clay soil (10, 20, and 30 ton/ha of ash) an increase in moisture content in weight percentage compared to the control sample was observed. The overall result of this test showed the positive effect of ash on water retention.

To measure the infiltration, instructions for measuring water penetration rate were used in the double-ring field method from Iran's water industry standard (1981- A-84). Based on these instructions, two cylinders with a diameter of 30 and 60 cm and a height of 30 cm in form of concentric were hammered inside the plot and the permeability was measured with accuracy. To estimate the amount of water penetration into the soil and its changes with time in different soil textures and climatic conditions, the Lewis-Kostiakov equation was used, and results were found to be satisfactory.

Figure 3.24 Measuring infiltration by double ring method

Determination of the average penetration rate of water in the soil

In the experiments conducted on different treatments, the average penetration rate of water to soil was studied. The results showed that 10 ton/ha of ash had no effect on loam clay soil, but 20 ton/ha increased the permeability, which showed a positive impact on the ash. In the 30 tons treatment, the average penetration rate of water to soil was reduced, the reason could be the loss of effective porosity of the soil. Also, *koul* decreased the permeability of Loam Sandy soil at 10 and 20 ton/ha, while at 30 ton/ha increased the average permeation velocity. In clay soil, as the ash increased, the average permeability rate increased, but the process was stopped at 30 ton/ha. (Presented in Table 3.2)

Table 3.2 Average penetration rate (cm/h)

	Ash		witness	Treatment type
ton 30	ton 20	ton 10		Soil type
1.02	1.68	1.22	1.19	Clay Loam
1.91	1.60	1.73	1.83	Sandy Loam
1.26	2.36	1.032	0.904	Clay

The water penetration rate in the soil:

Compared to the control treatment, in clay loam soil, the water penetration rate of soil increased in treatments of 10 and 20 ton/ha of ash but in the treatment of 30 ton/ha, the penetration has decreased due to the reduction of effective porosity of the soil. In loam sandy soil, koul had a little effect in the treatment of 10 ton/ha and showed a decrease of penetration rate in 20 and 30 ton/h of ash. (Presented in Tables 3.3)

Table 3.3 The rate of penetration of the water in the soil

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Ash			witness	Treatment type
ton 30	ton 20	ton 10		Soil type
0.002	0.017	0.004	0.003	Clay Loam
0.010	0.007	0.014	0.013	Sandy Loam
0.003	0.03	0.004	0.002	Clay

The treatment of soil with ash was tested on 1-ha of apple orchard. The conventional growth period was 175 days with an average irrigation interval of 6 days requiring 10,460 m^3 of irrigation water along with a pre-irrigation requirement of 30 mm water depth. Each irrigation cycle consumes 431 m^3 of water. Based on the experiments and the overall moisture penetration, Loamy-clay soil was treated with 20 ton/ha of ash.

Increasing the irrigation interval from 6 to 8 days, along with treatment of soil by adding 20 tons of *Koul* (ash), eliminated eight irrigation cycles from the irrigation plan (saving about 3,448 m^3 of water). At the end of the period, an increase in yield due to an increase in irrigation efficiency was observed. Thus, about 27% of the water in the growing period could be saved by treating the soil with *Koul.*

The total area under cultivation of horticultural and crop products in *Zanjan* province is about 1,86,000 ha, which consumes 1.5 BCM of water each year. Considering the access and availability of *Koul*, a bare minimum of 10% water can be saved, amounting to 150 MCM annually. This method is very cost-effective and will be beneficial for farmers, especially in drought-affected areas. It can be used in the greenhouse cultivation phase and in rain feed cultivation for a variety of crops and treatments.

3.8.5 Less Water Use through Rural Community Participation and Technology Transferring by the Private Sector in Urmia Lake Basin

Submitted By: Mr. Hossein Dehghanisanij, Mr. Majid Mirlatifi and Mr. Vahidreza Verdinejad (2019)

Lake *Urmia* is in the North-Western part of Iran between two West and East Azerbaijan provinces. The area of the lake has gradually shrunk since 2000 with the decrease in water inflow mainly because of the drought and the increase in the water outflow largely for agriculture. Water management practices were required to avoid the complete drying of the lake.

The traditional farming practices were changed with the use of newer technologies and by community participation with the support of the private sector in the development and management of *Urmia* Lake basin. The conventional method of surface irrigation was advanced by better agronomic and management techniques such as crop fertilizer management, pest and disease management, cultivation techniques and crop management, improvement of conventional surface irrigation systems, irrigation management, optimization of irrigation plots, using winnowed seeds, using seeds with a shorter growth period. The techniques saved water by reducing water loss in evaporation and deep percolation, improved water holding capacity, and decreased irrigation time.

The implemented techniques' affect water application, yield, water productivity on wheat, barley, rapeseed, garlic, and sugar beet cultivation were studied. Training and farmers' skills in planning and decision-making for on-farm management indicated that on-farm water application reduced the water requirements between 5% and 45% compared to conventional methods. Water productivity increased in all the treatment farms. For example, wheat water productivity increased by 14% to 63% in the treatment and control field. Increased productivity in barley fields was between 21% and 32%. The water productivity of sugar beet increased by 39%.

Several private agricultural engineering companies (PAEC) were set up for providing training services to farmers in the *Urmia* Lake basin. Experts from PAEC prepared the training materials and equipped the trainers to communicate with farmers. The focus was on capacity building, knowledge dissemination, green technology, stakeholder participation, empowerment, and increased human resource skills rather than the transfer of hardware technology.

The empowerment and involvement of local communities in the rural sector and small landholders was the prime objective of the project. Some documentation was required to get approvals by local agricultural offices to support and encourage the private sector in other villages and regions. Some handbooks for introducing the technologies and their application were written by extension offices.

Figure 3.25 Introducing (a) Raised bed planting (b) Introducing furrow irrigation for trees instead of flood

Figure 3.26 Measuring water inflow to the farm by WSC flume

3.8.6 Water Loss Reduction by using Geo-Synthetic Clay Liners (GCL): Underlining of Irrigation Canals

Submitted By: Hamidreza Khodabakhshi, Maryam Pashmforoosh and Farshad Esmaeil Zade Feridani (2018)

Khuzestan province is in the southwest of Iran with large irrigation and drainage networks. High seepage from the constructed irrigation canals in this province has increased water losses and reduced transfer efficiency in irrigation networks that are significantly important today given Iran's dry and semi-dry hydrological conditions. Therefore, preventing water losses caused by seepage by waterproofing canals became an important and effective step towards achieving water use efficiency. One such waterproofing material is Geo-synthetic clay liners (GCLs), specially designed for *Khuzestan*.

The major constraint in designing and constructing canal networks is the regional soil conditions. About 80% of irrigation and drainage projects of *Khuzestan* face issues like dispersive, liquefied, collapsible, swelling, and gypsum soil which impose very high costs on designs followed by a long construction period. One solution is preventing direct contact with water by using an impermeable layer. The popular method for waterproofing irrigation canal sections worldwide is using the impermeable geo-synthetics such as all types of geomembranes (GM) including HDPE, LDPE, LLDPE, VLDPE, PVC, and geo-composites.

In this innovation, Geo-synthetic clay liners (GCLs) (a manufactured hydraulic barrier consisting of clay bonded to a layer or layers of geo-synthetics) have been used because of their self-healing properties. Due to the presence of bentonite in its structure, it has a high ability to bear asymmetrical settlements, excellent adhesion to concrete, quick and easy installation, and low hydraulic conductivity than other impermeable layers. The irrigation and drainage network of *Dasht-e-Arayez* covers 28,285 ha in seven areas. In addition to sand and gypsum lenses in some parts of the project line, high water losses, network canals' seepage, wetting, and flooding were the main reasons for waterproofing the sections of the canal. GCLs or GM-GCLs with their extraordinary sealing properties and very low hydraulic conductivity (10-12 to 10-14 m/s) underlining irrigation canals dramatically reduced seepage and water losses from irrigation canals. The main canal section before GCL lining and after GCL lining is shown below in Figures 3.27 and 3.28.

Figure 3.27 GCL installed section underlining of canal

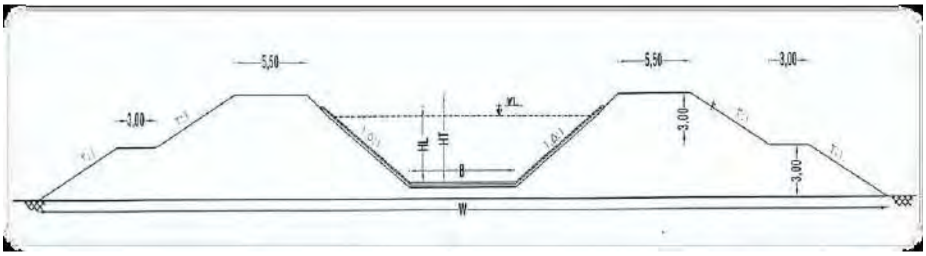

Figure 3.28 AMC canal section

There is no accurate seepage information in canals without GCL in these regions; there is no exact basis to calculate water loss reduction. But monitoring of those canals with GCL showed no seepage. Therefore, if the seepage of these canals equals the seepage for canals with concrete lining (USDA recommendation), which is 0.03 m^3/m^2 day, these losses were reduced to 0-1.4 MCM/year.

The above technology was also applied to *Dasht-e-Azadegan* canals. The reported seepage was approximately 18.92 l/s for 1-km canal length (about 0.083 m^3/m^2/day) as a basis for the other parts of canals in non-GCL conditions. Water losses reduction was estimated by the assumption of reaching seepage value to 0.03 m^3/m^2/day (based on USDA diagram for concrete-covers), 0.02 m^3/m^2/day, 0.01 m^3/m^2/day, and 0 (by using GCL). The losses were reduced from 0.083 to 0.03, water loss reduction by using GCL was about 15.6 MCM/year, but it could be much more than that according to zero seepage in those experimental parts and up to at least 25 MCM/year.

It was found that GCLs are suitable for sealing and reducing water losses in irrigation canals with different specifications. It, therefore, can be used in irrigation canals in other parts of Iran and the world. Due to the diversity of impermeable geo-synthetics and concrete additives, this study can be done with different types of these materials. Due to the different mechanical properties of waterproofing materials, their long-term performance in canal sealing and durability of these materials (according to different environmental conditions) can be a subject for future research. Due to the different dimensions of the irrigation canals and the different construction conditions, it is important to study and select the sealant materials that have the highest B/C ratio.

3.9 IRAQ

3.9.1 Soil Water Retention Technology (SWRT) to Sandy Soil in Iraq

Submitted By: Shatha Salim Majeed (2017)

Plant water deficits are among the greatest limitations in optimizing plant growth potential. Supplemental irrigation, additional fertiliser, or manure applications to increase plant production on most sandy soils are simply not sustainable due to extensive leaching losses of water nutrients and pathogens to groundwater supplies. To control such deficits, technologies and innovative subsurface water-saving must be incorporated into agroecological management operations.

One such concept is Soil Water Retention Technology (SWRT) for converting sandy soils into productive soil. The main goal of this technique is to conserve up to 60% of the irrigation water required to produce vegetables. This was tested by installing spatially positioned impermeable sheets below the root zone to prevent water contents a little lower than field capacity from moving down below the depth of most roots. Sandy soils are generally characterized by having a weak structure and high infiltration rates, high hydraulic conductivity, low water holding capacity, and low plant nutrients. The soil restraints require SWRT membranes installed at depths below the root zone.

The techniques' objectives are as follows:

(a) Quantify increased water retention, reduced evaporation, and salinity when subsurface water retention technology water-saving membranes are installed at 55 and 40 cm depths in irrigated sands in central Iraq.

(b) Identify most strategic scheduling of supplemental irrigation to improve vegetable production by 50 to 100% on sandy soils treated with subsurface water-saving membranes.

(c) Minimize drainage and evaporative soil water losses at soil surfaces and surface plastic barriers to increase water use efficiencies, reduce fertilizer requirements resulting in 50 to 200% increase in tomato and other vegetable production.

Laboratory, greenhouse lysimeter, and field testing indicated SWRT membranes double the water storage capacity in the root zones of plants grown in deep sands without natural Bt horizons of fine clay. This new technology maximizes the conservation of water and nutrients to protect the environment and enhance soil quality and productivity. Many agro-ecological, environmental and hydrological attributes of the concept increase the quantity and quality of vegetables and grain crops while using fewer fertilizers and much less supplemental irrigation water.

The polymer membranes double the water and nutrients within plant root zones with the potential for dramatically reducing drought stress events for at least 25 days during a cropping season. They are an environmentally safe technological replacement of the missing natural water retention layers of fine clay, transforming sand soils into oases of cellulosic biomass and food production of vegetables, grains, and fruit. Additionally, these membranes modify sand soils with new components that enhance multiple ecosystem services- increases soil carbon sequestration, reduces fertilizer applications and leaching, reduces greenhouse gases, and reduces intermittent plant water deficits during extreme weather patterns associated with changing climate.

It was found that continuous monitoring of soil water contents can be achieved by decagon soil water content, temperature, and EC probes, installed at three soil depths equal to two above and one below the barriers of all soil and irrigation treatments. Timing and rates of supplemental irrigation scheduling for each treatment can be controlled by the readings of these soil probes. The goal is to keep volumetric soil water contents in the root zones of all treatments at or nearly the same. Once the soil water and solution instruments are installed, surface soils are prepared, plastic surface covers are laid down before peppers and tomato seedlings are transplanted. Continuous measuring of water use efficiency is based on plant height, biomass, plant production, and quality following each harvest, and soil water removed from the different soil depths minus the deep drainage. Peppers and tomatoes can be harvested every week until they mature.

These approaches achieved 30 to 400% increases in crop yields while using 40 to 80% less supplemental irrigation water. This research has demonstrated that subsurface soil water-retention technologies installed within plant root zones are self-regulating technologies that improve food production and increase water use efficiencies by retaining more water and nutrients in the root zones. Comparisons of SWRT yields with controls can be coupled with yields in the region for best estimates of crop yield, water savings, and other ecosystem services to the vegetable markets in Iraq.

Prediction models of the techniques' enhancements of water and nutrient conservation to soils across Iraq can be assembled into compelling presentations to motivate users and policymakers. A three-growing season project that demonstrates success on 8-10 farms and several experiment stations can adequately demonstrate the transferability of knowledge and the direct application of SWRT packages for sustainable production coupled with expanded ecosystem services for multiple soil types and the sandy knolls of undulating topographies of finer textured soils.

Current research plans are expanding SWRT into Arizona, Florida, Missouri, and Kansas. As with most new technologies, markets for these industries are relatively steady initially. However, once market returns for value-added higher-yielding produce are realized, manufacturing will increase logarithmically for decades to come. As demands for food increase, commodity prices rise and biomass production for biofuels becomes more profitable, larger quantities of newly cultivated landscapes, including sandy soils will be brought into profitable agricultural production.

3.10 ITALY

3.10.1 Weather Monitoring and GIS Technologies for Sustainable Water Management

Submitted By: Nazzareno Diodato (2010)

Within the irrigation industry, multivariate spatial statistics techniques can be efficiently applied to generate fine patterns of climate data in presence of an appropriate structure over ungauged mountainous basins. However, they are unsuitable when the data available over complex regions are sparse and affected by discordant spatial scales in primary and (colocated)-auxiliary variables. This is the case of actual evapotranspiration (AET).

Therefore, by combining GIS and geo-indicators (e.g., topographical and vegetational indices), an upscaling procedure was developed to overcome this problem, transforming a preliminary smooth macro-scale pattern (AET grid-data), into a local-scale pattern.

The innovation was introduced by Met European Research Observatory (MetEROBS)-and GISLab. This unique record allows investigation of climate parameters in the *Apennine* zone of Southern Italy through two current projects (TEMS FAO) and GEWEX-CEOP of the World Climate Research Programme.

The procedure was applied to a cropland test site at the Mediterranean sub-regional basin scale (*Tammaro*, South Italy) to develop a climatological baseline estimation of AET refined at the slope scale. After the upscaling, the most frequent estimated AET values were about 550 mm/year (with quasi-normal distribution), while underestimations were observed in the preliminary, smoothed map (a positively skewed distribution with mean 460 mm/year). The upscaling allowed the influence of the topographic factor to emerge, with a wider range of values (about 300–900 mm/yr−1) being estimated and substantially not visible in the smoothed pattern. A temporal climate pattern of soil water depletion in the growing season was also shown as reflected in the increase of AET flux in the period 1991–2008 in comparison to the precedent climate (1961–1990). An attempt was made to assess the relative influence of different controlling factors on water-and-soil conservation and ground-water recharge. Spatio-temporal variations of rainfall, potential evapotranspiration, ground-water draft, and consequent water-table fluctuations were analysed using GIS.

The analysis performed in this study focused on an important water cycle component (evapotranspiration) at multiple scales, where catchment is the typical scale of water resources planning. A topographically weighted radial basis function was used to generate evapotranspiration data in conditions of lack of a large climate dataset in water protection studies. Unifying the GIS approach and reanalysis proved useful to overcome the restrictions associated with analysing local temporal datasets, like limited records. This is relevant for sustainable agricultural water management and conservation.

Further study is required to compare the results obtained on different spatial resolutions via simulation models and spatial statistical approaches that can deal comprehensively with the problem of error propagation. This will involve comparing the model output from low resolution, low accuracy input data to model output from high resolution, high accuracy input data at various disaggregation levels.

3.11 LEBANON

3.11.1 LARI-LEB App to Support Lebanese Small Farmers for Improving Water Productivity and Managing Irrigation Requirements

Submitted By: Dr. Marie Therese Abi Saab (2020)

Lebanon is a Mediterranean country currently experiencing severe water shortages. The Lebanese Agricultural Research Institute (LARI) manages a network of over 60 automated weather stations. This network is very useful to assist agricultural communities in managing their practices and available water resources more efficiently. The efficient use of water resources saves water, energy, and money.

In recent years, information, and communication technologies (ICTs) have been increasingly used in water management. These innovations make studying water needs and availability easier and improve water productivity. However, translating and transferring this information and solutions to local and small farmers are hindered by many factors, including silo design.

LARI developed a mobile application called LARI-LEB, which provides daily weather information to the public, especially farmers. This information includes weather forecast for a maximum of 10 days; update of cumulated rainfall amount (after every rainy day) with comparison on the mean and previous rainy season; recorded maximal and minimal temperature; alert regarding heatwaves for farmers; irrigation suggestions; alert before expected frost; suggestions to reduce the risk; wind storms alerts; pest outbreak alert based on field observation mentioning the area of the outbreak and crop, along with pest control measures based on climate forecast, and farmers' suggestions and procedures (sowing, harvesting, pruning); news and events and general information for all users. More than 30,000 adherents joined this service.

However, LARI-LEB app lacked relevant information for on-farm irrigation management and crop health that supported local farmers to understand better 'when' and 'how much' water to apply and how their crops are progressing during the season. Such a module helps farmers to monitor crop growth and let them understand how much fresh yield (Kg/dunam) would be expected since the planting time. Therefore, new modules for irrigation and crop health management were co-designed and co-developed within LARI-LEB App. This technology was conducted within the framework of a project with the International Water Management Institute (IWMI) and FAO focusing on using ICT to improve water productivity. IWMI-MENA office was appointed to support, upgrade, and promote the LARI-LEB App in Lebanon. The irrigation management and crop health modules in LARI-LEB app were developed using the FAO portal to monitor Water Productivity through Open access of Remotely sensed derived data (WaPOR dataset. https://wapor.apps.fao.org). WaPOR uses satellite information to compute and map key variables related to water and agriculture, such as evapotranspiration, biomass production, and water productivity. The LARI-LEB App was upgraded to support smallholder farmers of the *Bekaa* valley (area 4000 km^2) for irrigation management and crop health of selected main crops: wheat, potato, and table grapes using wheat, potato, and table grapes remote sensing and local data.

The main idea was to provide the farmer with one value corresponding to the Net Irrigation Requirements NIR (mm/day). Therefore, the farmers were given access to the NIR map. The map showed the same legend colours for the different NIR classes/ranges. The farmer had to locate their field and its colour on the map. H/She then selects the grown crop and the corresponding irrigation method. The app provides the gross irrigation amount GIR (m^3/day/dunam). After that, by providing information related to the field size, water emitter flow, distance between emitters, and rows, the farmer gets the irrigation duration in hr/day/field size.

The crop health module in LARI-LEB was based on data derived from the remote sensing open-access database of FAO-WAPOR. More specifically, the Net Primary Production (NPP) map layers were used. The NPP is a fundamental characteristic of an ecosystem, expressing the conversion of carbon dioxide into biomass driven by photosynthesis. The crop health module was designed according to flowchart parameters - Crop Health Module- Harvest Index, Dry matter- NPP layers/GIS, Maps of cumulated NPP for different planting times- Cumulated fresh yield in farmer field. The farmer opens the module, selects a crop and the planting time, and the app provides him with one value corresponding to the cumulated fresh yield in their field from planting time until now (Kg/dunam).

Currently, there are over 600 small farmers registered users of the app. LARI-LEB App supports irrigation operators and helps them assess systems' performance to identify the focused investments to modernize their irrigation schemes. Moreover, government agencies benefit from the app by using the information to monitor and promote the efficient use of natural resources.

For the phone app to be effective and sustainable, it must be regarded as a part of an integrated development approach with end-users as farmers. It requires day-to-day technical and organizational efforts from the governmental authorities. It cannot wholly replace agricultural extension services and face-to-face communication with farmers in the field.

3.12 THE NETHERLANDS

3.12.1 Drip Planner Charts for Small Holders Drip Farmers

Submitted By: Mr. Harm Boesveld (2012)

Wageningen University and Research Centre developed the Drip Planner Chart (DPC) to provide small-scale farmers with a simple manual tool to schedule drip irrigation according to crop needs.

Irrigation scheduling has been an important topic in agricultural research for several decades. There is a vast amount of literature on irrigation scheduling and water management. Over the last years, several irrigation scheduling computer models have been developed. There is a large and widening gap between the state-of-the-art irrigation scheduling tools and current on-farm irrigation practices. Big commercial farms and smallholder farmers make little use of the scheduling tools for various reasons. Most producers find the state-of-the-art irrigation scheduling tools overwhelming and lack the skills necessary to install, operate, and troubleshoot them. Many smallholder farmers, especially in developing countries, lack the financial means to buy expensive equipment, and many have no computer to run the models. It was realised that farmers need simpler, cheaper, and more comprehensive support tools to achieve improved irrigation management at the farm level. This led to the inception of DPC.

The DPC is a simple manual chart to determine the irrigation requirement of various crops. A specific chart was developed for fruit crops (citrus, banana, grapes, and pineapple) and vegetable crops (tomato, cabbage, carrot, onion). It consists of two disks: one disk with crop and climatological data to calculate the irrigation requirement. The second disk translates the irrigation requirement of disk 1 into practical advice on the number of drums to irrigate plot/day. The crop water requirements of the DPC are based on the FAO method, which is based on evapotranspiration and the crop factors depending on the crop's growth stage. Four distinct growing stages are distinguished during a growing season. Input ET_O values are acquired from nearby weather stations or agricultural extension services. For a chart developed for a particular region, it is possible to assign standard weather conditions by analyzing the probability levels of ET_O in that area during different seasons. This could even lead to the use of icons, for example- sunny during the dry season, cloudy, dry season, and others. For the irrigation requirement, the rainfall and the irrigation system's efficiency come into account. Possible other water sources like rain or capillary rise are accounted for to determine the irrigation requirement. Capillary rise is only substantial in soils with a groundwater table close to the root zone. In many arid/water-scarce areas, this can be neglected.

International Development Enterprises (IDE) promotes Low-Cost Water Technology to poor rural farmers to improve their livelihood. In 2008, Wageningen University collaborated with local offices of IDE in Zambia and Nepal to introduce the DPC. The DPC was first tested and demonstrated on farmers' demonstration plots. DPC was refined and adapted to the specific farming conditions of the Zambian farmers.

Drip irrigation is mostly new to smallholder farmers with little educational background. Research in Zambia and Nepal revealed that farmers have no scheduling tool to base irrigation applications on and often apply flat water rates regardless of the crop's growth stage or the climatic conditions. DPC is a simple tool that helped the farmers to apply water according to the needs of the crops. Water savings of 15 – 50% were recorded in Spain, Ethiopia, Zambia, and Nepal. DPC is now promoted to all farmers adapting Low-Cost Drip technology.

3.13 PAKISTAN

3.13.1 Wheat Bed Planter

Submitted By: Prof. Dr. Rai Niaz Ahmad (2009)

Raised Bed Technology has immense potential to achieve high irrigation water-saving and increased crop yield. Many researchers have reported that bed planting offers better weed control. Water management and fertilizer use efficiency and less crop lodging are also achieved. Based on implementation reports from 2009, it has been further reported that bed planting increases yield by at least 10%, reduces production cost by 20-30%, and saves irrigation water up to 35% compared to conventional planting. Therefore, bed planting can be considered one of the most feasible water conservation techniques to improve irrigation application efficiency in Pakistan.

However, the non-availability of proper machines in the country is a significant constraint in bed planting for grain crops. Thus, there was a dire need for a well-designed Wheat Bed Planter for achieving water-saving consistent with better yields.

The wheat planting machine was improvised to plant various crops on beds directly, especially corn. It is the first mechanical machine developed locally for making beds and at the same time having provision of seeding corn, wheat, and cotton, the major crops of this region.

The Wheat Bed Planting Machine has the following salient features

(a) Planting mechanism on beds: The bed planting machine develops two beds and three furrows in a single operation. It is designed to plant four rows on one bed. A furrow for irrigation separates each bed. There is a buffer zone in the centre of four rows on the bed. The machine develops two lines of the crop on both sides of the furrow. Each furrow has to irrigate only 20 cm of the adjacent beds. The centre-to-centre distance of two beds is 90 cm with a bed of 60 cm. Thus, the machine has the provision to plant 4 lines in 90 cm width while maintaining the traditional plant population. The machine has also a provision of adjusting planting depth.

(b) Furrow and bed size: The machine has an adjustable furrower/furrow opener, which enables the development of variable sizes of the furrow if desired. There is an adjustable planer on the machine to level the bed top for facilitating precise planting.

(c) Fertilizer application directly on beds: Wheat Bed Planting machine has the provision of direct fertilizer application along with sowing on the beds, which avoids extra fertilizer application in the furrows and ensures efficient seed nutrition in the bed.

The machine was tested at the Water Management Research Centre (WMRC) and promoted by establishing demonstration plots on farmers' fields at *Okara* and *Faisalabad* as part of an ongoing research project. The findings are presented below:

The water-saving and increase in yield for the crops were tested on wheat, cotton, maize, and rice under different plot sizes. The plot size varied vastly for these crops, such as wheat (10 ha to 290 ha), cotton (10 ha to 118 ha), maize (15 ha to 110 ha), and rice (10 ha to 30 ha).

The water-saving under wheat was 51.3%, cotton was 47%, maize was 45.4%, and rice was 31.1%. The corresponding increase in the maximum yield was 25.2%, 11.7%, 29.5%, and 25.1%, respectively. The average water-saving with different plot sizes and under different locations varied on average as wheat (45.5%), cotton (43%), maize (42.4%), and rice (30%). The corresponding average increase in the yield was 16.8%, 11.7%, 26.7%, and 25.1%, respectively.

Wheat under-bed planting resulted in a 16.8% increase in yield with 45.5% water-saving. According to Pakistan Economic Survey 2007-08, 21,749 000 tons of wheat were produced from 8.41 Mha with an average yield of 2585 kg/ha. Adopting this bed planting machine for sowing wheat under raised bed technology witnessed an increase of 3,654 000 tons in production.

Moreover, the water-saving of 45.5% under-bed planting reflects that the complete replacement of conventional method by Raised Bed Technology at 8.41 Mha will save water for another 3.83 Mha land, which was about 60% of the then fallow land in 2007-08 (6.44 Mha).

3.14 SOUTH AFRICA

3.14.1 Irrigation Scheduling with Irricheck Software and Services and DFM Probes

Submitted By: Willem Van Aarde (2011)

Karsten Farms, one of the largest irrigation farming enterprises in the Republic of South Africa, grows mainly table grapes for export on 1,082 ha on nine farms on the banks of the Lower Orange River between *Upington* and *Klein Pella*. In the same area, grapes for wine and raisins, citrus, dates, watermelons, sweet melons, maize, wheat, onions, potatoes, and pomegranates are grown on 732 ha. They also farm deciduous fruits on 187 ha nearby Ceres in the Cape Province and nuts, corn, wheat, and vegetable seeds on 1000 ha nearby Prieska in the Northern Cape. At least fifteen managers and forty-five watermen (workers who apply the irrigation and maintain the irrigation systems) are involved in the planning and executing of the irrigation on close to 600 irrigation blocks.

Up until 2007, Karsten used neutron moisture meters for scheduling their irrigation. In February 2008, the Irricheck Irrigation Scheduling system was introduced on the farm. It improved the accuracy of their irrigation scheduling, led to quicker and informed decision making, reduced the labour requirements, and made the whole management a seamless process. During 2008, the system was evaluated with six probes. In 2009, 2010, and 2011 additional probes were gradually added until today with 350 probes on 255 irrigation blocks.

The Irri-check Irrigation Scheduling system:

The computer program automatically “draws” the weather forecast via the internet and the actual weather data from an automatic weather station. The actual evaporative demand according to the actual weather data and the expected evaporative demand according to the weather forecast is calculated using the Penman-Monteith equation. The soil moisture is measured continuously every hour at six depths by DFM soil moisture probes. The probe data is collected twice a week using a portable data logger. The probe measurements (%) are calibrated to volumetric water content (mm/m).

The program automatically integrates the hourly soil moisture data, the evaporative demand, and the information of the crop-, soil- and the irrigation system to calculate the required irrigation for each irrigation block for the coming week. The system provides information that allows the accurate refinement of parameters like safe depletion levels and crop factors. The program continuously calculates the ratio between water used and actual evaporative demand. When this ratio drops, it indicates that soil water supply is restricted, and water stress occurs. The deficit at this point is the maximum depletion level, while the ratio occurring before this drop is the crop factor. Because all the calculations are automated, the system allows management to delegate routine scheduling to lower levels of management. Managers can easily check the results in easy-to-access graphs and tables.

The program automatically checks all data and warns users if something needs attention. Examples: Warnings are issued if a probe battery needs to be replaced, any probe sensor is unstable, probe data from a field is not collected in a given period, or when the deficit on a field exceeds a certain critical level. These warnings can be displayed on the computer screen or sent by SMS to the responsible person. This feature makes delegation safe for management and provides a full-proof irrigation scheduling mechanism.

The system enables the user to determine the maximum safe depletion level, maximising irrigation and minimising evaporation losses. The longer irrigation intervals help to create soil conditions with more oxygen for root and microbial life.

It leads to quick and better decisions due to the accurate refinement of parameters such as crop factors, field water capacities, and application rates. For example, both water use and evaporative demand are measured and the crop factor is calculated automatically as the water used is divided by the evaporative demand.

The purpose of irrigation scheduling is not confined to saving water only, but it also optimizes water use. In most cases, crops are over irrigated and under irrigated for shorter periods from time to time. The scheduling system can therefore lead to an increase in water use efficiencies.

On the farms with the system installed, the water usage as measured in pumping hours was reduced by 34% on average during 2009 and 2010 compared to 2007. On the 1,814 ha of irrigation land of the Karsten Group in the Lower Orange River area, a 27% water-saving was witnessed equivalent to approximately 7,346,700 m^3 which is sufficient to irrigate an additional 671 ha.

3.14.2 Virtual Irrigation Academy (VIA) to improve Water Productivity

Submitted By: Richard Stirzaker and Joe Stevens (2020)

The idea of building a Virtual Irrigation Academy for smallholders arose from the realization that traditional ‘science-based solutions’ to water management were not effective enough. A digital tool was developed that aligned with the mental models of the farmer to build upon their existing experiential knowledge. For a simpler understanding, a tool was designed to provide outputs as colours indicating thresholds for action, thereby creating a new ‘language’ of water for farmers. Moreover, the language of colours and patterns made the tacit knowledge of the farmers explicit, which could be learned together by placing farmers at the forefront of identifying local solutions for their unique constraints.

Virtual Irrigation Academy (VIA) was designed to transform the small-scale irrigation sector through three functions:

(a) Easy to understand water and solute monitoring tools
(b) An experiential-based learning system and
(c) A water governance system

The VIA comprises a suite of soil water and solute monitoring tools that give output as colours, coupled with an online visualization platform. The VIA was launched in 2016, and is now active in 15 countries, and has accrued a database of over 1700 monitored crops.

The Chameleon soil water monitoring device of the VIA is comprised of three sensors that are inserted into the soil and above ground logging that visually shows farmers whether the soil water status is: wet (blue light), moist (green light), or dry (red light). The sensors measure soil water potential, so the colours have the same meaning concerning crop stress, regardless of soil type. The sensor array is ID chipped, and the Chameleon reader is Wi-Fi enabled, so data is sent to the VIA online platform at https://via.farm/, where colour patterns can be visualized by farmers and researchers. As the crop progresses, the percentage of blue, green, and red colour in the Chameleon pattern is calculated by averaging over depth and time. For example, an over-irrigated crop may be 90% blue, 10% green, and 10% red. Farmers quickly learned that if the Chameleon pattern is mostly blue at all depths (<20 kPa), they are likely to leach nutrients. Thus, farmers were motivated to reduce the amount of blue on their patterns and aim for the green (20 to 50 kPa), which was captured in their patterns. The result was a higher proportion of green and red, and yields were obtained in the 4 to 8 ton/ha range.

It was found that all 20 irrigators in a scheme in Tanzania reduced the number of irrigations by at least 1/3rd after seeing that the Chameleon sensors were usually blue (wet) and that the Wetting Front Detector showed them that they were leaching nutrients. Although only 10% of farmers in the scheme were involved in the project, the new knowledge became so widespread that farmers at the tail end of the scheme, who had historically experienced water shortages, reported sufficient water in the canals for the first time.

Based on comprehensive farmer surveys in Mozambique, Zimbabwe, and Tanzania, it was reported that the influence of the VIA tools went beyond the farmers who had them installed on their plots. For example, it was reported that only one-quarter of farmers on a scheme received VIA tools, but three-quarters of the farmers reported using less water and getting substantially higher yields. In a mid-term review of the VIA project sites in Malawi and Tanzania, the Association for Strengthening Agricultural Research in East and Central Africa (ASARECA) listed the benefits of the VIA as i) increasing yields ii) reducing conflict over water iii) reducing water use iv) improved gender relations v) better delivery of extension services vi) more job creation and vii) increased profitability.

An unanticipated benefit of the VIA was its utility for women and youth. Chameleon sensors allowed women to avoid water conflict and enabled them to negotiate on equal terms. They also benefitted from knowing when to skip irrigations, with reports of labour savings of one full day per week or more. Since the technology is mobile-based, the youth population’s participation in agriculture can also increase.

3.14.3 SAPWAT 3: Irrigation Water Planning Tool

Submitted By: Messrs Pieter S Van Heerden and Charles T Crosby’s Work (2011)

In South Africa, the major rivers are already over-extended, and irrigation uses about 60% of the total water supply; good planning and management of irrigation water are of utter importance to increase irrigation water use efficiency. Irrigation water managers required an easy-to-use planning tool to estimate water requirements and enable the right amount of water supply at the right time.

A user-friendly computer model was developed that enabled irrigation water users to plan the amount of irrigation water required by an irrigation farm, an irrigation scheme, or a water management area monthly. This tool, SAPWAT, was a further development of CROPWAT and is being used by more than 300 users in 13 countries, even though it was designed against the background of South African needs. SAPWAT 3 the latest version of the computer model is not a crop growth model. It is designed to allow the user to imitate the situation in an irrigated field through interaction. This allows the user to do “what if” with different irrigation scenarios to see the effect of a specific management decision on irrigation water requirements. Some characteristics are as follows:

Data Management: The program has data management facility, including big data sets. The data is stored onboard for easy access and addresses the limitations of web accessibility. CLIMWAT, CROPWAT weather data have been included along with daily data of 5,100 weather stations. Daily data for any number of successive years is used to do year-on-year irrigation requirement estimates, which allows the user to include risk analysis as part of the planning process.

Crops: 104 crops are included in the crops data now expanded to 2,500 crop records by providing for differences in growth and development because of different planting types at different times of the year and in different climates.

Salinity stress and water stress situations can be imitated. This module works from two sides. The effect of stress on yield is displayed, or the user can also define a level of yield reduction to stretch the water need. If yield reduction is defined, the program will apply water stress, so that yield reduction reflects the required level.

All irrigation requirement estimates can be stored and revisited to determine what effect changes in irrigation water management, irrigation system, and changes in planting dates could have.

The editing functions of weather stations allow the user to adapt data to represent predicted climate change scenarios, which can predict irrigation water requirements under climate change situations. “Now-then what-if” scenarios could be set.

Data can be exported for use in other applications, such as for use in spreadsheets. A module for small (back-yard) water harvesting situations where the amount of water required for a small garden can be estimated. Runoff from roof and/or adjacent hard-packed surfaces and storage requirements are determined. Maximum garden size for balance with harvest area and storage is calculated. Pumping times with low technology pumps such as the treadle pump is also calculated. Large data sets can safely be handled. The weather data amounts to about 38 million records.

SAPWAT3 Model

The program allows the user to manage all the background data that SAPWAT3 uses. These include crops, irrigation systems, soils, area water distribution systems, weather stations, enterprise budgets, countries, and addresses. Köppen climate definitions are also given, but these are read-only. The user does an area, farm, field, crop set-up to reflect the area of work. Provision is made for back-wards summation of crop irrigation requirement to field, farm, and area irrigation requirement. The efficiencies of irrigation water reticulation systems at different levels are included in this calculation.

The crop for which irrigation requirement needs to be estimated is defined in terms of weather stations and climate, soil type, irrigation system, planting date, foliage cover, yield, area planted, and irrigation management strategy. For year-on-year irrigation requirement estimates, subsets of the weather data, such as a period that is known to have had a below-average rainfall, can be selected.

The results are graphically displayed as crop coefficient, evaporation, crop evapotranspiration, and soil water content over the growing season.

Further results show monthly and total irrigation water required for different levels of non-exceedance and levels of efficiency of irrigation water use and rainfall use efficiency. Daily water balances can be inspected, specifically for identifying water stress situations.

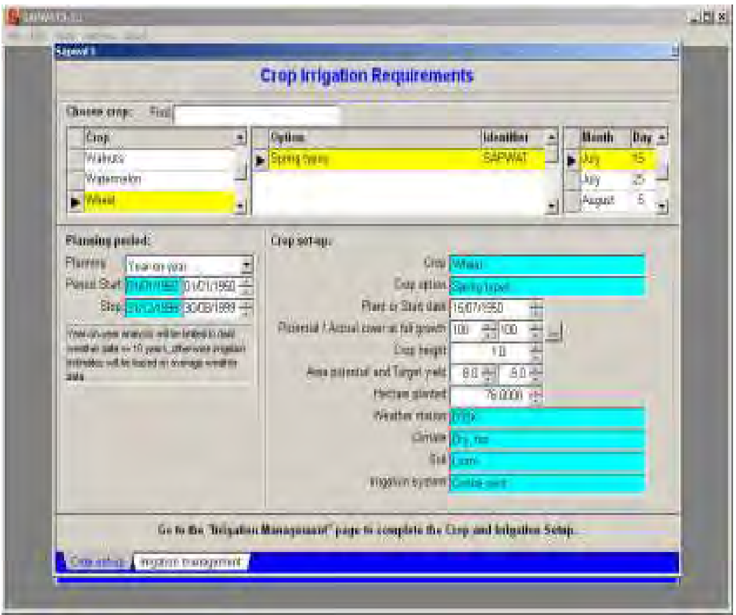

Figure 3.29 Graphic presentation of crop requirements

SAPWAT3 is used by irrigation designers in South Africa to optimize water use to its fullest extent. One such case is short grower maize planted on 15 December. If the irrigation strategy is to make the best possible use of rainfall by not filling the soil profile to field capacity during irrigation, the irrigation water required is 320 mm. If the irrigation strategy is changed to always fill the soil profile to field capacity, which results in low rainfall use efficiency, the irrigation requirement is 500 mm. Irrigation water-saving by using the better strategy amounts to 180 mm, or 36%. If this saving is translated to the 1.5 Mha irrigated in South Africa, total annual irrigation water-saving could amount to 27,000 MCM.

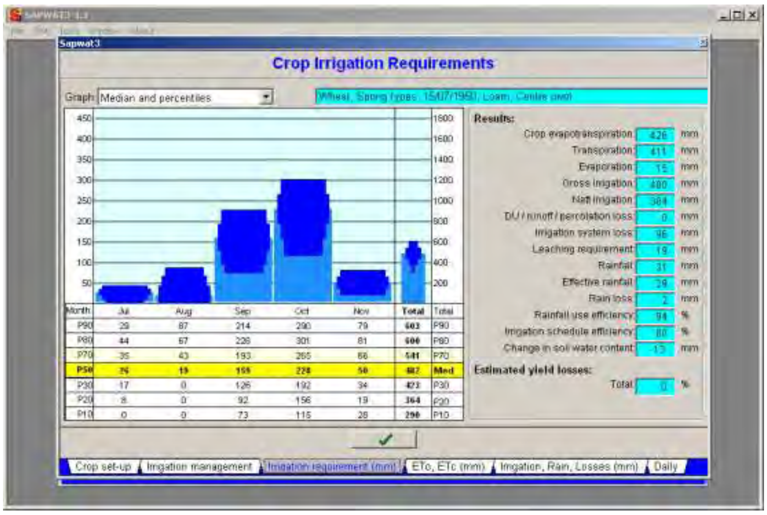

Figure 3.30 Crop Irrigation requirement screen

The SAPWAT3 has been fully endorsed by the Department of Water Affairs in South Africa as a tool to issue water licenses for irrigation purposes. A survey amongst users about one year after publication shows that 51% found it a useful tool and that 46% found it easy to use. Apart from application in South Africa, SAPWAT3 has been used in Angola, Mali, Mozambique, Namibia, Niger, Swaziland, and Uzbekistan for irrigation system design and irrigation water use planning.

3.15 SPAIN

3.15.1 Promoting Shade –Cloth Covers On-Farm Reservoirs to Mitigate Evaporation Losses

Submitted By: Dr Victoriano Martinez Alvarez (2012)

On-farm reservoirs for irrigation are required worldwide but are most relevant in arid and semi-arid areas where water resources are often scarce and irregularly distributed throughout the year. Such reservoirs are typically used in the South and Eastern parts of Spain to cope with the variable water allotments and periods without supply, thus guaranteeing water for irrigation all year round.

In arid and semiarid regions, evaporation losses from water storage represent an important percentage of the stored water. More specifically, more than 15,000 on-farm reservoirs in the *Segura* Basin (South-Eastern Spain) estimated their annual evaporation to be in the order of 60 MCM, which corresponds to 8.5% of irrigation water use. Important evaporation losses have also been reported in numerous water-stressed regions worldwide. It is important to assess such losses and their economic impact and apply scientific knowledge to develop and promote technical approaches for their mitigation.

One such innovation was Suspended Shade Cloth Covers (SSCCs) which saved between 80-90% of annual evaporation losses in on-farm reservoirs. Suspended Shade Cloth Covers consist of a porous fabric supported by a double reticulated frame structure made of steel or polyamide cables, which is anchored to the water storage's surrounding wall. The fabric is attached between the frames and suspended over the water surface. Shade fabrics range from single-layered white, green, blue, aluminized, or black polyethylene to specifically designed double-layered black polyethylene. The selected fabric (optical properties and porosity) and the height at which it is suspended above the water determines its efficacy in reducing evaporative loss.

The demonstrations were held in more than 100 on-farm reservoirs in South-Eastern Spain, saving about 0.5 MCM/year in 500 ha of irrigated land. The use of SSCC was generalized in the *Segura* Basin and about 50 MCM/year of water lost by evaporation was saved. From a physical point of view, the presence of the covers substantially affected the radiative and aerodynamic exchanges from the water surface to the surrounding air. The reduction of the radiation load over the water surface is the main factor explaining the high efficiency of the SSCCs and depends on the optical properties of the cover material. The wind-shelter effect of the covers reduces the aerodynamic exchanges under the cover, which are inversely proportional to the wind-shelter capacity of each fabric, and actively contribute to evaporation reduction. In addition to preventing evaporation, covers were also permeable to rain. The promoted SSCCs allowed recovering approximately 90% of the rainfall.

Another positive aspect to consider is the effect of SSCCs on water quality. Several benefits were observed on the properties of the stored water when shade covers were installed. These benefits included the dwindling of algae growth due to the lack of sunlight under the cover, the prevention of debris deposition, and lower salt concentration in the water volume when the balance between rainfall and evaporation was positive.

From a merely practical point of view, the SSCCs have been proven to be an effective water-saving technique for on-farm reservoirs operating under high evaporative demand, with black fabrics significantly outperforming other covering materials. Additionally, the covers severely limited the activity of photosynthetic algae, thus reducing filtering requirements in drip irrigation, with the consequent improvement in water and energy use efficiency.

3.16 TURKEY

3.16.1 Water Powered Pump (WPP)

Submitted By: Sahin Bekisoglu (2013)

Water Powered Pump (WPP) is a unique technology contributing to water use efficiency that was implemented in *Kayseri* Province*, Sara* town *Yaylaci* village in 2010. WPP uses the kinetic energy of the stream water and does not require any electric energy, diesel motor, and petroleum products such as diesel fuel, gasoline, or natural gas. It can be used everywhere, with a small drop from the stream water. It can supply water for irrigation, domestic or other requirements. It is environmentally friendly and converts the unused energy of the stream water for pumping a certain volume of water to a calculated head. The existing experiences and well-known scientific knowledge have been used to create and invent the WPP. Some of its features are presented below:

WPP's capacity depends on the stream water volume, drop height, pumped water volume, pumped height and system efficiency. It can be calculated by using mathematical, mechanical, and hydraulic formulas. The water turbine dimensions are calculated by using stream water data, and pumping water head and volume. The total system efficiency also affects the pump's effectiveness.

Water hammer was invented for pumping water to higher elevations by using the kinetic energy of the stream water. The capacity of the water hammer is limited and is not very effective for high elevations. WPP completely differs from water-hammer and other types of centrifugal pumps. It has a water turbine (water wheel) directly connected to a double-action piston. The stream water rotates the water turbine and circular movement changes to a vertical movement by a crank. The vertical movement of the piston connection rod pushes and pulls the double-sided piston, which moves forward and backward inside a cylinder. When the piston goes backward a negative pressure occurs inside the cylinder, the suction valve opens by itself and the piston sucks the water inside the cylinder.

At the same time, the other side of the piston pushes the water to push the pipe. When the action continues, piston sucks the water by one side and pushes the water to the other side to an air tank. The pump sucks and pushes the water to the regulation tank by a two-sided acted piston without stopping. The air tank prevents water flow in the push pipe and eliminates the water hammer backpressure. The water outlet comes from the air tank by the push pipes. The water turbine and the pump are directly connected, and the system loss decreases while the productivity of the WPP increases.

Q= 19 l/s capacity irrigation water has been pumped up to 54 m elevation by WPP free of charge in the last three years.

Q_1 = Stream water capacity (l/s) = 300 l/s

H_1 = Drop height (m)= 5.0 m

A_1 = Water turbine efficiency= 0.83

H_2 = Pumping head (m)= 54 m

A_2 = Pump efficiency= 0.83

Q_2 = Pumped water capacity (l/s) = ?

Water energy is equal to: $N_e = Q_1*H_1*A_1/75$ = HP

Pump energy is equal to: $N_p = Q_2*H_2*A_2/75$ = HP

$N_e = N_p \Rightarrow Q_1*H_1*A_1*A_2 = Q_2*H_2$

300 l/s capacity water * 5 m drop height*0.83*0.83 = Q_2 *54 m

300 * 5.0 *0.83* 0.83= Q2*54 Q_2= 19.1 l/s = 68 m^3/hour= 1640 m^3/day= 49,200 m^3/month

Q = 19 l/s capacity water is sufficient approximately for a 20-ha land for surface irrigation.

If the farmer implements drip (trickle) irrigation, it will be sufficient for 35-40 ha land. This amount of water will be sufficient for the 10,933 people's domestic water usage at 150 l/day/person. If the stream capacity and drop height increase the pumped water amount also increases or vice versa.

WPP turned dry land into irrigated land without using electric energy, diesel fuel, and gasoline. It provided the necessary pressure for drip and sprinkler irrigation. Drip irrigation saved around 40-50% and sprinkler irrigation around 20-30% of the irrigation water. Using this unique pump, Yaylaci village farmers saved approximately 40-50% of irrigation water. If the farmers used electric energy to pump the irrigation water, they would have used 70,000-80,000 kWh of electric energy every year. Turkey's electric energy price is 0. 20 USD/kW (0,36 TL/kWh). In this case, the farmers saved 14,000-16,000 USD/year. Given the diesel prices and the quantity required, farmers saved around 14,000 t of diesel and around 31,000 USD/year. Almost 3.3 billion kWh of electric energy was used by the farmers for pumped irrigation water in the country in 2012. This also reflects the huge impact WPP can create on the ground if used in all the farms. Other benefits of using this innovative pump are reduced dependence on non-renewable resources like diesel, simple and scalable methodology, almost negligible maintenance costs, environmentally sustainable technique, and higher agricultural produce.

3.16.2 Aquarius – Intelligent Irrigation Control System

Submitted By: Aydin Oztoprak (2013)

Aquarius is a smart irrigation technology. It releases the right amount of water at the right time, and at the right location. It measures the humidity in the soil and automatically adjusts the humidity level according to the crop and soil characteristics. It can wirelessly communicate with other units and can get a reliable measurement of large fields. Aquarius is the first proof of concept that might apply to most smart valves. It was first designed for large crop fields, but the concept can be applied at any scale for irrigation. It can be applied to lawn irrigation and the irrigation of large parks and golf courses. Some of its features are explained below:

An automatic irrigation control system works by measuring the humidity of the soil and selects the most efficient irrigation pattern based on the pre-set crop type, soil characteristics, and climate conditions. The system consists of a solenoid valve, humidity sensors, processing unit, battery pack, solar cells, and wireless communication unit.

The system senses relative soil humidity and reports to its processing unit. Based on the pre-set conditions for the crop, the processing unit permits water discharge or not. If permitted, water it instructs the solenoid valve to open the gate. During irrigation, the system continues to measure the relative humidity of the soil, if a certain value is reached, the processing unit instructs the valve to close the gate. Although the working principle is simple the underlying structure, electronics, and programming behind Aquarius are complex. The innovative irrigation technology operates autonomously in the wild without electricity infrastructure, it needs to be rugged, and communicates wirelessly with the user. It utilizes solar panels and a battery pack to operate unattended in the wild without electric infrastructure. Although solar panels recharge the battery pack continuously during the daytime for constant operation, they have a battery pack that is sufficient for a week without charging. It has a serial port and telemetry connection to receive and transfer data.

Aquarius has been designed to reduce water consumption in agricultural irrigation, which is the largest portion of water consumption in the world. By sensing the moisture in the soil, it increases the irrigation efficiency and effectiveness ultimately saving water. Usually, farmers tend to overflow fields with open irrigation and use excessive amounts of water, which in turn causes almost 60% of water to be wasted. In recent technological applications like drip irrigation farmers tend to use water all day long. Innovation systems like solves this problem as it evaluates humidity right from the soil, even for flood type open irrigation.

The direct effects of implementing Aquarius are the dramatic water, electricity, and labour savings in the short term. The system delivers the exact amount of water at the exact time without human intervention. The indirect impact is the preservation of soil from salinity, higher yield rates, and awareness on the preservation of natural and economical resources as well as the implementation of high technology in agriculture.

In Turkey, saving even 15% of irrigation water can compensate for water consumption in domestic water usage. Hence, this innovative system can become the next big thing for the industry.

Aquarius has a great potential for further improvements and variations. The required investment compared to the anticipated gain is extremely high. It has the potential to save water as much as total household water consumption.

For further implementation, the concept of smart control valves can be applied to other sources of water consumption. However, the biggest water consumption is in agriculture and industrial applications. Aquarius is a proof of concept that data-based water-flow control technologies are successful in saving large amounts of water and can revolutionize agricultural development.

Figure 3.31 Aquarius and its functioning on the field

3.17 UNITED KINGDOM

3.17.1 Irrigation Water Security: Promoting On-Farm Reservoirs in The UK

Submitted By: Keith Weatherhead, Melvyn Kay, And Jerry Knox (2010)

Most irrigation water is abstracted from local rivers and streams in the UK and is used immediately with relatively little on-farm storage. The volumes are a very small proportion of the national total water use, but they have a significant environmental impact because they are concentrated in the driest parts of the country and at the driest times of the year when resources are scarcest. The growth in irrigation water demand is rising at 2% per annum. Climate change will increase demand further, while Summer River flows and water availability will be reduced.

This technology promotes the use of on-farm reservoirs to store surplus winter water for use in drier summers. The construction of on-farm reservoirs has provided the water security essential to achieve timely production of high-quality food that reduces water wastage from field to plate. With this objective, the farmers in the UK invested in reservoirs in the drier parts of the country, to secure water supplies for irrigating high-value fruit and vegetables. Farmers with a winter-filled reservoir have an assured supply for their summer irrigation needs, and the environmental impact of irrigation abstraction is reduced during the summer months when water resources are most constrained. However, there were economic, technical, and regulatory issues to resolve to achieve wider uptake of on-farm reservoirs. This innovation has addressed these issues.

Figure 3.32 On-farm reservoirs

On-farm storage of higher flows during winter was an obvious solution. Once the water is in the reservoir, farmers can plan to crop for the following year. Reservoirs store the high winter river flows for use in the drier summer period. The water thus 'conserved' is then 'saved' for other domestic, industrial, and environmental uses during the summer months.

Farmers with a winter-filled reservoir have an assured supply for their summer irrigation needs, and the environmental impact of irrigation abstraction is reduced during the summer months when water resources are most constrained. Evidence from EEDA over the past year showed that 18 agri-businesses in the eastern region have applied for grant funding for reservoirs totalling over 2 MCM and involving a private investment of over 6 million GBP. However, challenges in adoption included planning, safety, environmental, leisure, and even archaeological which hampered reservoir developments and discouraged investment.

A key recommendation from 2006's consultations on agricultural water strategy was shared reservoirs that enabled investment and benefits to be spread among groups of farmers. Environmental regulators and governmental bodies responsible for business sustainability actively encouraged farmers across the region to rethink the role of on-farm storage.

Subsequently, a detailed technical report and an information booklet *"Thinking about an irrigation reservoir? – A guide to planning, designing, constructing, and commissioning a water storage reservoir"* was prepared and disseminated to over 2,500 farmers and agri-food businesses across the eastern region which invited private investments for the reservoirs.

Following the success in the eastern region, it further expanded to the Southern and Midlands Regions where high-value crops were irrigated in water stress areas. Steps were taken in the development and implementation of water strategies for both agriculture and horticulture with funding support from the Environment Agency, rural development agencies (e.g. EEDA), and grower levy boards which provided support to their growers (e.g. Horticultural Development Council). This provided the necessary framework within which future water issues for growers and the agri-industry can be addressed.

Water storage techniques are a key to the success of irrigation development and meeting the water needs when there are no rains or the source to meet the irrigation water requirements.

Figure 3.33 A way through the obstacle course for farmers wishing to build an on-farm reservoir

3.18 UNITED STATES OF AMERICA

3.18.1 Benefits of the South San Joaquin Irrigation District's Pilot Pressure Irrigation Project

Submitted By: Er. Jeff Shaw And Todd Kotey (2014)

A growing population and competing demands for limited water resources prompted California-USA to pass the Water Conservation Act. In addition to a 20% reduction in per-capita urban consumption by 2020, the law required agricultural suppliers to "implement efficient water management practices" and volumetric pricing. With a state-wide assessment of water use underway, the South San Joaquin Irrigation District (SSJID) Board of Directors realized the issue posed a potential threat and approved the Division 9 pressure system upgrade to demonstrate that the district is proactively addressing California's conservation goals.

The SSJID historically delivered water to farmers through 400 miles of gravity-based canals and pipelines. Farmers drew from the network of laterals at scheduled times via flood irrigation or private pumps used for sprinkler or drip systems. While the system worked well for flood irrigation, the combination of flood and sprinkler usage on a single system became problematic. As a result, some customers did not buy water from the SSJID, opting instead to draw from their private, salinity-stricken wells. With the new pressure system, the customers increased, and efficiency was improved.

The newly approved Division 9 pressure system efficiently managed water delivered by reducing water needs by up to 30% and accounted for water use through magnetic flow meters at each customer connection.

A portion of one of the district's nine divisions – 1537 ha in Division 9 – was chosen as the site for building, testing, and optimizing a pilot pressure irrigation project. The vision for the system included the following fundamental capabilities:

(a) **Pressurization –** pumping water from a 56-acre-foot pond to individual farms through 19 miles of pressurized pipeline

(b) **Calculated use –** letting farmers choose the time, volume, and flow rate of deliveries

(c) **Automated/mobile access –** developing a web-based tool that allows farmers to schedule deliveries from a computer, smartphone, or iPad based on current and past weather forecasts, previous water usage and historical evapotranspiration rates, and orchard moisture sensors.

The project consisted of a 19-mile network of pipelines with flexible pressurization (currently set at 60 psi), a 56-acre-foot water storage basin, a 1,225- hp (913482 W) pumping station containing seven vertical turbine pumps capable of pumping a total of 23,500 gal/min (52.4 ft^3/s), and a total of 55 solar-powered Field Telemetry Units or FTU's controlling 77 customer connections. The FTU consisted of a PV panel, a flow control valve, and meter, and a radio-based supervisory control that communicates with a data acquisition (SCADA) system in the pump control room.

With the Division 9 pressure system, each customer had one connection point, with a magnetic flow meter to measure and transmit water deliveries; historic data are automatically stored on the district's server for uploading into the district's billing software.

With the new system, irrigation water was distributed to the customers across 3,800 acres of California's Central Valley through an automated channel. Using an online system similar to an airline ticketing platform, growers were able to login and schedule water deliveries. Additional information on current and past weather forecasts, previous water usage, historical evapotranspiration rates, and real-time moisture sensor readings were also available on the website. Each farmer selected from available delivery dates and received alerts via email and text message before and after delivery to confirm volume and flow rate data. To promote efficient water usage, moisture sensors placed in the ground on each grower's property indicated optimal ordering times when orchards were at their greatest need.

The survey revealed that the customers received irrigation water at the exact time, flow rate, pressure, and duration they needed. In addition, the reduced number of customers using the gravity system allowed the flood runs to be accomplished faster and more efficiently, with less stress on the previously overloaded gravity system and reduced long-term maintenance costs.

The survey data indicates as follows:

(a) With the Division 9 pressure system, Farmers were able to irrigate based on surface water availability and crop water requirement, at the exact flow rate and duration they desired. With the pressure system upgrade, the district proactively addressed California's conservation goals. The system efficiently managed water delivered by reducing water needs by up to 30%

(b) The farmers in the SSJID service area have historically been charged a flat rate of 24 USD/acre for irrigation water. A typical 40-acre orchard has numerous valve structures to flood irrigate the land. This posed a difficult and expensive challenge for the district to comply with due to the thousands of exits points off of the gravity system. However, in the new system, each customer has one connection point, with a magnetic flow meter to measure and transmit water deliveries. The historic data are automatically stored on the district's server for uploading into the district's billing software, complying with the Water Conservation Act.

(c) The district's fixed, the 10-day delivery schedule does not provide an optimal water supply at the frequency needed to maximize crop yield. The system's East Basin Pump Station doubled as a regulating reservoir, storing and pumping irrigation water to 77 customer connections on an on-demand basis, the pressure system induced a demand to convert from flood irrigation to sprinkler/drip application methods. Of the 77 customer connections in the system, 18 installed sprinkler or drip systems immediately after the pressure system was available to serve their land. The increased use of sprinkler/drip increased the irrigation efficiency of the farming operation and contributed to the goal of maximizing beneficial use of the district's water rights.

(d) The system tapped into abundantly available solar energy in the region to meet the power demands of all of the customer connections. The solar system powered the solenoids of the flow control valve, magnetic flow meter, moisture sensors, process logic controller, and radio communications to operate the turnouts and provided real-time information on flow rate, crop moisture conditions, turnout pressure, control, and battery component status, and delivery details (start time, end time, total hours irrigated, average flow rate, total water delivered).

(e) The ten-year average water supply (2002-2011) to the Division 9 pressure system customer base has been 7,528 acre-feet. The summation of water deliveries (calculated via magnetic flow meters at each customer connection) through the pressure system for the first year amounted to 4,695 acre-ft. Thus, a 2,833 acre-ft conservation has been achieved.

On a water delivered per acre basis, the savings magnified because 50% of the customers of the pressure system were using their wells before the pressure irrigation system. Now, the District was able to re-enrol these farmers and reduced groundwater pumping while higher quality surface water use increased. Before the pressure system, 19,924 acre-ft of water was delivered to Division 9 to support 3,151 acres, or 6.32 ft of water per acre. Water deliveries for the pressure system customer connection for the 2012 irrigation year amounted to 4,695 acre-ft to support 2,389 acres, or 1.96 ft/acre of water. The system reduced the acreage pumping from the groundwater aquifer by 50%. Groundwater pumping in the area was primarily conducted using diesel-driven pumps. The reduction in diesel emissions improved the air quality, and the high-quality surface water improved crop (primarily almond and walnut orchards) health.

Farmers participating in the pressure system used the direct injection of fertilizer at their filter stations and delivered chemicals directly to the root zone area; thus reduced the deposition of fertilizer in the local surface and groundwater.

To provide a manageable pressure system for both the SSJID and the customers, a user-friendly software interface was developed. Tools at the farmers' fingertips to plan their irrigations included national weather service alerts for the area (including frost and wind alerts), weather forecasts, Doppler radar imaging, customizable and exportable/printable charts on past weather (rainfall, wind, temperature, humidity, evapotranspiration rates), water deliveries (time start, time end, total hours irrigated, average flow rate, and total water delivered), and moisture sensor information.

Although data evidence on the increase in yield due to the Division 9 pressure system will take some time, other case studies reveal that farmers will see a 30% increase in yield. With increased control of irrigation timing, duration, and application rate, there has been a marked decrease in pests and diseases associated with water delivery. A major benefit was the consolidation of pumping operations.

Due to the new surface water-based pressure system, there was a considerable reduction in the pumping of salinity-stricken groundwater. Farmers reduced flood irrigation and utilized drip, micro, and solid-state sprinklers to irrigate their land, which improved crop yield, conserved water by up to 30%, and reduced erosion and deposition of fertilizer into local surface and groundwater.

The pilot project showed a marked benefit over the conventional system; therefore, the same can be extended and replicated to other areas as well.

3.18.2 Nebraska Agricultural Water Management Network: Integration Research and Extension/ Outreach

Submitted By: Dr. Suat Irmak (year)

In the United States, approximately 26 Mha are now being irrigated, and about 13.5% of this total is in Nebraska alone. The total land area under irrigation in Nebraska has increased from about 1.7 Mha in 1970 to 3.5 Mha in 2007.

Maximizing the net benefits of irrigated plant production through appropriately designed agricultural water management programs is of growing importance in Nebraska and other western and Midwestern states. Today, in many areas of the world, including Nebraska, farmers are being challenged to practice conservation methods and use water resources more efficiently while meeting plant water requirements and maintaining high yields. Another challenge farmers experience is the limited adoption of newer technologies/tools for better irrigation management, water and energy conservation, and water use efficiency. A comprehensive water management system was implemented to overcome these challenges, which increased water use efficiency in the region.

Currently, irrigated agriculture in Nebraska faces ever-increasing pressure to do their part to conserve water, protect water quality and maintain sustainable agro systems. The long-term viability of this resource is threatened by several consecutive years of drought and over-pumping of groundwater supply. These have reduced well output and falling groundwater tables in much of the *Ogallala* aquifer. Litigation between “downstream” and “upstream” users has restricted the amount of water available to farmers in some major watersheds. In Nebraska, these constraints require limits on the amount of irrigation water that can be pumped by farmers, restricted or regulated drilling of new irrigation wells, and require flow meters on existing wells in some parts of the state. The rising cost of fuel and the limited water availability make producing maximum grain yield with minimal input imperative.

Scientific and practical management strategies are needed that can aid the decision-making process to enhance plant water use efficiency to achieve maximum profitability. These challenges also mandate water use monitoring methods or devices for better-informed irrigation management decisions. Poor irrigation management strategies further contribute to the reduction in available water resources. All these issues can be encountered through well-designed, large-scale, coordinated, and effective irrigation water management programs. These programs can be delivered to the user via a variety of dissemination tools, including one-on-one interactions with field demonstrations, seminars and courses, and web resources.

Figure 3.34 Crop water use device implemented in the NAWMN

Figure 3.35 Soil moisture sensor devices implemented in the NAWMN

Figure 3.36 One-on-one training of a farmer in the field

Figure 3.37 Demonstration of soil moisture measurement in the field

In 2005, the Nebraska Agricultural Water Management Network (NAWMN) (http://water.unl.edu/web/cropswater/nawmdn) was formed from an interdisciplinary team of partners including the Natural Resources Districts (NRD); United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS); farmers, crop consultants; and University Extension. The NAWM has saved, on average, 2 inches of irrigation water per season and the network represents about 1.5 million acres of croplands. The impact of the network on savings both water and energy in agriculture was substantial with about 1 BCM of water savings and a total of more than 40 million USD in energy savings. The NAWMN helped participants to improve irrigation management and efficiency by monitoring plant growth stages and development, soil moisture, and crop water use. As a result, they reduced irrigation water application amounts and associated energy savings leading to greater profitability to producers.

All demonstration projects related to increasing crop water productivity and water and energy conservation were supported by scientifically based field research and evaluation. Extensive demonstration projects established in farmers' fields were used to teach on-site experiences about using new tools/technologies for water conservation. Training on reading sensors/instrumentation and how to implement the information into their water management operations were also provided.

This interdisciplinary demonstration project has been very effective in helping farmers to increase the adoption of appropriate newer technologies and methods to obtain higher water use efficiency and save water and energy resources. The network has since then enhanced the communication and information exchange between farmers, researchers, NRCS, UNL Extension, NRDs, and other state and federal agencies.

The first four years of results and collaborations with growers yielded excellent outputs and positive feedback from core members and producers. The ET gages and watermark data were analysed, and core members and producers learned about using both the ET gages and watermark sensors and incorporated them into their irrigation management decisions. Growers reported water conservation and energy savings. For example, based on the survey conducted in 2008, estimated water conservation was averaged at 66 mm for maize and 55 mm for soybean on 1,14,000 ha (58,000 ha of maize and about 56,000 ha of soybean). With 2008 diesel fuel prices, this water conservation was an equivalent of 2,814,000 USD and 2,270,000 USD for maize and soybean, respectively, in energy costs saved for the land area represented. This interdisciplinary team effort has demonstrated that a well-coordinated team effort comprised of farmers, researchers, educators, and state and federal agency personnel is an effective approach to conserve water and energy resources through effective irrigation management.

4. WATER-SAVING MANAGEMENT TECHNIQUES

BACKGROUND

This chapter lists and briefly describes the nominations submitted through ICID national committees since 2009, and they represent vast geographies, cropping systems, diverse institutional frameworks, and temporal-spatial characteristics. While it is well known that irrigation solutions as such cannot be simply imported to a place, scientific management interventions with relevant adjustments can certainly be explored and contemplated in new places.

The saying that "we can only manage what we can measure with a certain degree of confidence" does indicate the importance of data-driven management decisions in any situation. It would become clearer as we go through the WatSave nominations received in the Management category of the awards. Data collection and their use in decision-making can easily be identified as the most common feature among the nominations. Modernization of old irrigation systems using newer technologies and streamlined management functions are also visible in the nominations. Quite a few nominations fall in the category of successful "community-based" approaches.

4.1 AUSTRALIA

4.1.1 Trangie-Nevertire Renewal: An Irrigation Infrastructure Modernisation Success Story

Submitted By: Mr. James Winter and Mr.Tony Quigley (2019)

Trangie-Nevertire Co-operative Ltd (TNCL), a member-owned irrigation scheme, pumps water out of the Macquarie River in the central west of New South Wales-Australia (NSW) that had reached its use-by-date in the middle of the Millennium Drought. The combined impact of high conveyance losses, a series of low or zero water allocation years, the threat of losing water, and the possibility of government's buying back the saved water from the members and ever-increasing costs, led to the general realization that it is high time to modernize the water use system.

To apply for the government funding, a strategic plan from a cooperative membership base, which quantified the issues, was developed for a modernization feasibility study, comprising of the following 5 major elements:

(a) Reducing the earthen channel system from 240 km to 138 km and retiring 17 members permanently from the irrigation scheme to improve sustainability.

(b) Rebuilding the remaining 138 km of channel system, lining 108 km with Firestone EPDM rubber membrane, and installing a complete Rubicon water gate system, all enclosed within electric animal exclusion fencing.

(c) Installing a 230 km pipeline from the river to all continuing and retiring farms to replace the previous reliance on the channel system.

(d) Modernizing the remaining members' on-farm irrigation infrastructure, with 24 linear move or centre pivot irrigators installed, as well as upgraded field layouts, tailwater return systems, and storages.

(e) Decommissioning the irrigation infrastructure on retiring farms and reconfiguring them back to a dryland basis, including piped stock and domestic water reticulation.

The water savings in the modernization project came from 4 main areas:

(a) The lining of 138 km of the rebuilt main channel with EPDM rubber led to a massive reduction in seepage losses. The selection of Firestone Geo Gard EPDM for the channel liner was a major leap of faith as the product had never been used on such a large scale in irrigation channels worldwide. The inclusion of the automated Rubicon Total Channel Control system substantially increased the water delivery service level to the members, allowing on-time and accurate on-farm water supply and measurement.

(b) The combination of the technologies reduced the channel conveyance losses from a historical average of 25% (ranging between 20% to 50%) to 7%. A substantial volume of rainfall was captured and stored in the lined channel sections, often providing the initial pool fills before the pumping season. This led to the farming members having more water available at the farm gate as compared to the pre-project stage.

(c) The Stock and Domestic pipeline system exceeded all expectations, with over 90% water savings, and available clean pressurized river water around the year as compared to linked irrigation supplies. In years of low or no irrigation allocation, such deliveries were either unavailable or with very high wet-up losses, which meant thousands of ML needed to be pumped to deliver only a couple of hundred ML into open dams. This also resulted in a huge improvement in livestock health and human amenity, especially during droughts.

(d) The on-farm infrastructure up-gradation led to water savings and increased yield for summer and winter crops. Most of these projects were based on replacing traditional furrow surface irrigation with overhead sprinkler centre pivot and linear move irrigators. Water use on the predominant cotton crop with these machines reduced by around 1 ML/ha while crop yields rose by 0.45 ton/ha, leading to a 30% increase in water use efficiency. Rotational winter crops have also shown improvements, especially in chickpeas where surface flood irrigation would often damage the crop from phytophra root disease, but the sprinkler irrigation allowed controlled application rates, prevented waterlogging, and enabled higher yields.

As a result of this project, channel conveyance losses have been reduced and on-farm productivity improved from greater water availability and promoted the installation of “state of the art” farm irrigation systems. Previous off-farm and on-farm irrigation losses are now being used for environmental benefit.

Given the system’s success, Narromine Irrigation Board of Management applied EPDM to a substantial length of their channel system using the TNCL developed laying system as part of their modernization plan. There is substantial scope for this channel lining system to be adopted across Australia and worldwide wherever seepage losses in open channels are a significant problem.

4.1.2 Integrated Water Recovery Provides Regional Growth for Northern Victoria

Submitted By: Mr. Peter Mccamish (2012)

Northern Victoria Irrigation Renewal Project (NVIRP) delivered a large-scale irrigation modernization project in the Goulburn Murray Irrigation District (GMID). This region is responsible for approximately 25% of the state’s agricultural production and contributes around AUD 1.45 billion per year to dairy and agricultural industries.

NVIRP provided an irrigation system that improved customer service levels, leveraged farm efficiencies, and increased productivity and profitability. Some of the features are presented below:

The 6,300 km irrigation channel network in operation for a century encountered inefficiencies due to record low rainfalls and long-term drought. NVIRP improvised the system to provide water at irrigator’s near-on-demand with higher and consistent flow rates facilitating increased opportunities and optimized water use efficiency and productivity. The project led to the installation of over 2,716 Rubicon gates and major control structures and 117 km of channel lining with over 1,000 metered outlets decommissioned.

Full automation of the system reduced the scheme's carbon footprint as the multiple daily manual adjustments of regulator gates and meters were no longer required. This significantly reduced the vehicle travel requirements too. Removing largely redundant assets reduced system water losses, increased operational efficiency, and reduced ongoing operations and maintenance costs – increasing the overall affordability of the scheme for current and future generations of irrigators.

Figure 4.1 Lined channel section with Rubicon control gates

Channels with high seepage and/or leakage rates were identified through a range of techniques such as soil maps, sandy soils, prior streams, aerial maps, leakage history (system operator), geophysics, field walks, and the operator's knowledge. These were controlled with automated mechanisms.

Improved metering to customers allowed better water management and reduced losses occurring at customer outlets.

Figure 4.2 Newly installed channel regulator structures

Figure 4.3 Old outfall structure

Irrigation modernization project under the ten-year program reduced system water losses and generated savings which benefited both the environment and consumptive water users.

NVIRP works closely with partner agencies such as the Goulburn Broken Catchment Management Authority to support other water-savings projects such as on-farm efficiency programs which leverage off the benefits of a modernized distribution system. The lessons learned and implemented water-saving technology over the four years of the project were further used in catchment areas and irrigation regions throughout Australia and more broadly around the world. The Murray Darling Basin Authority has indicated that there is a need to improve the management practices. It is well established that infrastructural improvements targeted at savings will also enable new investments in agriculture and other industries across the basin.

4.1.3 Development and Application of Innovative and Advanced Simulation Tools for the Evaluation and Optimization of Surface Irrigation Systems

Submitted By: Dr. Marcolm Gillies (2009)

Traditionally, the evaluation of surface irrigation water requirements for system improvement was based on data from a limited sample of furrows. Substantial spatial variability in soil infiltration characteristics and irrigation performance between furrows were completely ignored creating an erroneous evaluation of water requirements. Therefore, advanced simulation tools were developed to evaluate and optimise surface irrigation systems.

A model called SISCO solved the full hydrodynamic equation to simulate the hydraulics of multiple irrigation furrows and determined the optimum flow rate and time to give optimum performance for the whole field or a set of furrows. It had two components:

(a) **IPARM -** An inverse solution of the volume balance equation that allowed calculation of the time-dependent soil infiltration characteristic for a furrow or bay from measurements of the irrigation advance and runoff. The data obtained was used in an appropriate simulation model to simulate the irrigation and determine the best irrigation for the particular furrow or bay.

(b) **IRRIPROB -** A simulation tool to assist with managing furrow irrigation and the effect of soil spatial variability

An additional feature of this model was the graphical presentation of the interaction of the main performance measures and the user-specified objective function. SISCO, a new generation simulation model employed a solution of the full hydrodynamic equations. It was unique and unlike old simulation models, it could be applied to all surface irrigation methods, furrows, bays, level basins and drain back basins and performed the required calibration functions (inverse solution of the hydraulic resistance and infiltration parameters from the measured advance, recession, and runoff), simulation, and optimization in a single model. This calibration was also possible with limited data and accommodated user preferences in selecting the optimum or preferred irrigation.

The model worked on an inverse solution from the measured irrigation and other data to give the infiltration and surface resistance parameters prevailing during the measured irrigation. It conducted 'what if' simulations to determine the preferred flow rate and irrigation time. It used a simulation of the measured irrigation to calibrate and calculate the performance parameters for the measured irrigation. These improved evaluation tools can promote the uptake of the evaluation process among surface irrigators. The SISCO model could identify the surface resistance parameter as well as the infiltration characteristic and can use a wider range of measured data, for example, advance, recession, flow depths, and/or runoff. This improved the quality of the parameter estimates, the subsequent simulations, and the recommendations stemming from those simulations. It also allowed evaluations such as basin irrigation and irrigated bay pasture which were eliminated earlier. Even greater performance can be obtained if these systems can adapt to the different conditions prevailing at each irrigation.

Efficiency: With the new model, performance measurements across the main surface irrigated crops (cotton, grains, sugar, and pasture) showed application efficiencies ranging from 20 to 90% on average. Selection of more appropriate flow rates and irrigation times better suited to the specific soils achieved average efficiencies above 70%.

Expansion: Surface irrigation (furrow, bay, and basin) is a dominant irrigation method in Australia, used in 70% of the total area irrigated (1,000,000 ha). At the time, it was predicted that performance gains (i.e., water savings) above 20% could easily be achieved in surface irrigation systems through evaluation and practice change.

4.1.4 Water Banking – Conjunctive Water Use Management Approach for Water-saving

Submitted By: Dr. Amgad Elmahdi (2008)

All around the world, including in Australia, communities face water-related issues such as reduced water availability, conflicting water uses, and water-related environmental problems. Water shortage and deteriorating water quality contribute to a growing water crisis in many countries. Integrated water management in irrigated agricultural areas is the best strategy to optimize the use of available water resources in the face of reduced water availability, conflicting water uses, and other water-related environmental problems.

In the same light, a study was conducted on the Murrumbidgee River system to understand the viability of underground water banking as the new water storage and also a means of water-saving. This research investigated 'water banking,' i.e., storing water in an aquifer (an underground layer of gravel or porous stone that yields water), by creating a 50 m or deeper underground water bank.

Water banking refers to delivering water earlier than it is used and storing it into groundwater, so it is available to be pumped when required. In other words, redirecting surface water to subsurface water until it is utilized with zero evaporation losses. It is a unique water management technique that can test and assess the impact of the allocation of limited water resources between agricultural production and the environment. Water banking is defined as using, storing, and managing all surface and groundwater resources available as one single resource (using an aquifer as a storage system). Water banking can better manage biophysical demand and enhance instream flows that are biologically and ecologically significant.

Benefits of Water bank included: i) adding flexibility in conjunctive water management, ii) enhancing in-stream flows that are biologically and ecologically significant, iii) reducing water use in over appropriate areas, iv) reducing the impact of water pumping on to stream, and v) facilitating the legal transfer and market exchange of various types of surfaces, groundwater, and storage entitlements.

By combining system dynamics and multi-objective optimization with spatial and modeling data, an integrated hydrological-economic-environmental model was developed which helped land and water managers make decisions based on an evaluation of trade-offs between environmental, social, and economic factors. Farm, system, and catchment managers collectively optimised water resource management and distribution at both the short-term tactical and long-term strategic levels.

This technique along with an aquifer downstream of Murrumbidgee resulted in reducing system losses estimated at 200 GL, ranging from 12 to 14% river loss and 12 to 20% channel loss in Coleambally and Murrumbidgee Irrigation areas. Deep groundwater pressures declined by 10 and 20 m over most of the area. With each year an improved scientific understanding of the hydrologic system was developed; however, the role and capabilities of the water bank leave scope for future research. Using the aquifer improved the efficiency of the water distribution system and the natural seasonal flow of the river by releasing water from the head dams during the winter or wet months and storing it for recovery during dry months, the high demand period (Figure 4.4). This in turn improved the health of the river by freeing more water to the environment and mimicking the river's natural flow.

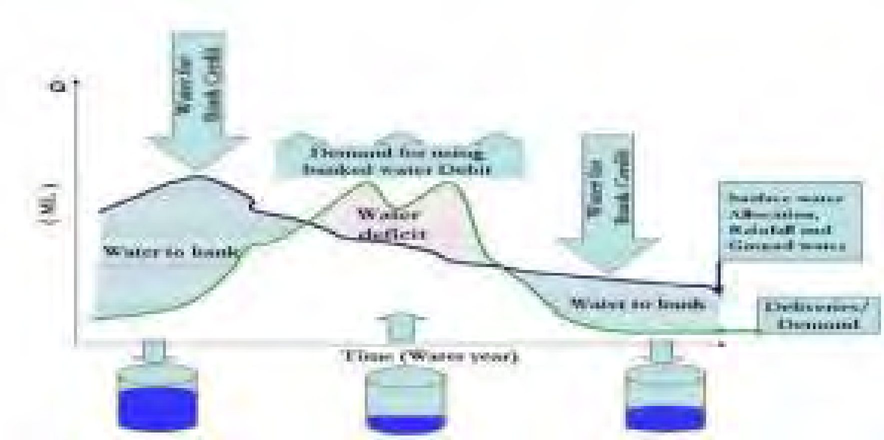

Figure 4.4 Water bank operational concept

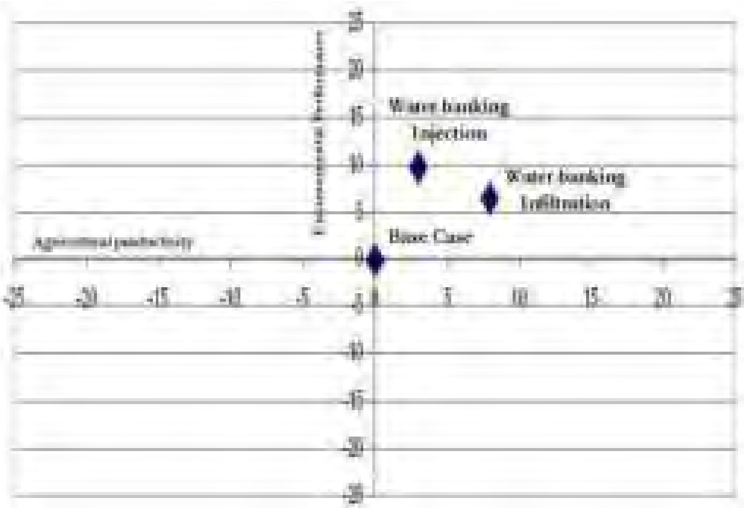

Figure 4.5 Water Trade off

Water trading has been tested underwater banking to facilitate water movement between irrigation areas or water banks. This study considered two artificial recharge methods with a changing crop mix option. The analysis indicated a clear trade-off between agricultural income and environmental performance to improve the seasonality of flows (Figure 4.5).

Water banking (storage and recovery water system underground scenario) by using infiltration and injection artificial recharge methods with changing crop mix improved agricultural income by 3 to 10% with potential water savings between 76 to 80 GL.

By using this technique, groundwater use could be reduced by 4 and 8%. The infiltration recharge method was more cost-effective than the injection where the river and aquifer system are connected. This integrated modeling framework is a useful policy and planning tool for catchment managers, water supply irrigation authorities, policy, decision-makers, and irrigators. It is a tool that has the potential to help stakeholders simulate and optimize the system, by evaluating and analyzing key decision variables. It can also provide a basis for examining the impact of physical changes to the system and for interactions with agricultural productivity, economics, and livelihoods to be predicted. For future expansion, the potential for artificial recharge sites using infiltration basins should be explored in detail to provide knowledge of evaporation-free, secure underground water dams. Additional economic water analysis needs to determine the water value under each use, such as environment, agriculture, and industry. Adding rainwater and water absorbed in soil moisture can add new dimensions to integrated catchment management with new degrees of freedom for water use to support both direct and indirect water needs. These could be facilitated by using a water banking approach to capture and manage different water resources with zero evaporation losses.

4.1.5 Dream-time Wholesale Nursery

Submitted By: Phillip Wratten (2013)

Dream-time Wholesale Nursery of Australia grows evergreen trees in 250 mm, 300 mm, and 400 mm containers for local councils, landscapers, retailers, thoroughbred racing facilities, and local farmers. It uses the NGIA Best Practice System in plant health, quality, pest and disease management, water management, staff training, staff safety, and all EcoHort procedures. The nursery is a modern facility that uses the latest innovative systems, most of which were developed in-house. This environmentally sustained nursery has installed a calcium hypochlorite treatment system to minimize pathogens, including regular water testing for recycled water with excellent drainage and run-off collection system, one of the best examples in Australia.

Water usage is controlled by a weather station that monitors rainfall and adjusts the watering schedule of the computerized irrigation system to minimize water usage. It does two essential things - conserves water reserve and reduces the carbon footprint on electricity use. Dream-time Wholesale Nursery has adapted to changes in garden design and has demonstrated the ability to grow drought-tolerant trees acclimatized to local conditions.

Dream-time wholesale nursery is an almost 100% recycling and self-sustaining model. All plant-growing bays are shaped to divert water to a central drain point. A trench is dug to remove water from the drainage system. All bays and trenches are lined with 200 mm virgin black sealed plastic. From the bays, central drain point agricultural drains are placed in sealed plastic-lined trenches back to the drainage system. 100mm of granite screenings are placed in bays for plants to be placed on. All bays, work much like a sink. Water is collected and returned to the drainage system. No water delivered by the irrigation system comes into contact with soil. Irrigation water is treated and filtered and returned to the nursery. All rainwater collected off roofs at the facility is used for drinking, staff facilities, and irrigating the various garden beds.

The nursery is over 11 ha in size and harvests rainwater from roofs. For every 100 mm of rainfall, the nursery collects 1.1 ML of water and returns it to the main dam. When linked to a weather station, the controller can be programmed with watering values to determine which crops require how much water after the rains.

A radio-controlled moisture sensing system is installed to determine water values in various crop growth stages and conducted over twelve months to assess crop values. Once crop values are determined for each season, they are programmed into the computer, which then analyses rainfall, if any, and irrigates per specific plant needs. When irrigating a crop, Omni-operated valves maintain a constant pressure so the total crop is grown with no variation in quality and minimize the operating time.

An automatic self-cleaning filtration system that reduces watering time is installed. Variable drive three-phase pressure control system maintains flow and reduces time. Three choice pots sprays are used to water all plants individually, catering to plant needs and not allowing overwatering.

A unique watering arm is installed to water plants as they come off the potting assembly line, which recycles back to the main dam. This eliminates the need for hoses as well. The Dream-time irrigation system is known not to use hand watering and saves over 1,50,000 l/annum.

Water quality is monitored, and records are updated monthly. Dreamtime also has environmental guidelines and sustainability targets. Regular risk assessment is conducted with checklists and records for efficient energy use, waste management, water reuse, erosion control, sediment trapping, and consideration to government regulations, neighbouring properties, and public roads, land, and soil management.

There are over 350 wholesale nurseries in the state of Victoria deriving water from a water provider. If Dream-time water-saving measures and systems are duplicated, with savings of say 30% on an average size nursery of 5 ha, savings equivalent to 2.5 BCM could be achieved in the state.

4.1.6 The Irrigate Public Open Space Code of Practice

Submitted By: Ipos Team (2010)

The Irrigate Public Open Space Code of Practice (IPOS) was developed by South Australia (SA) Water in consultation with various industry bodies in times of drought to reduce mains water consumption through irrigation of open space. The SA government required water savings of 20% across 16 metropolitan councils which were achieved easily whilst councils maintained their major assets.

The code is a tool for open space managers built around six key principles: 1. Policy and commitment; 2. Irrigation system performance; 3. Horticultural maintenance; 4. Determining baseline irrigation requirement; 5.

Management of irrigation schedule; and 6. Monitoring and reporting on performance. SA Water employees enforced these principles through a blanket governing policy. The technique was first introduced in 2007-08 to a limited number of metropolitan councils and gained momentum. As part of Water for Good (South Australia's securing water for the plan), IPOS was extended throughout rural councils and all schools across South Australia.

Irrigation benchmarks were set on high application efficiencies (LQDU = 80%), which encouraged permit holders to make the most out of their allocated water. Turf requirements were determined by monitoring evapotranspiration data made available by the Bureau of Meteorology. Soil monitoring was encouraged as it was recognized that evapotranspiration data can be different from the actual microclimate of one site.

Councils and SA Water identified major assets and irrigated them to a higher standard. Lower assets were given a lower irrigation requirement. These requirements were scientifically calculated using IPOS. Irrigation was based on 'fit for purpose' and occurred in line with the climate.

One strength of the IPOS code is it considers irrigation scheduling. It is important to note that there have been cases where efficient systems with high DU's were implemented; however, it did not lead to water savings. The correct precipitation rate and accurate refilling times were also calculated in this efficient system-managed irrigation scheduling. From an administrative perspective, the code provided the opportunity to respond constructively to legislators on how the 'Permanent Conservation Measures' could be varied in a way that would lead to higher yields and significant water savings.

Given the code's versatile application, it can be implemented in other parts of the world.

4.2 CANADA

4.2.1 Alberta Irrigation Management Model (AIMM), A Decision Support System

Submitted By: Mr. Richard Phillips (2018)

About 98% of Alberta's irrigation is in Southern Alberta, where more than fifty different irrigated crops are grown. Water is diverted from three rivers (Oldman, Bow, and St. Mary) and delivered to about 6,000 irrigation districts through an interconnected system of about 50 storage reservoirs and 7,900 km of canals and pipelines. Groundwater is not used for irrigation in Alberta. About 7,600 km of the canals and pipelines are owned and operated by the irrigation districts, and about 300 km by the Government of Alberta (GoA). Irrigation in Alberta was about 708,000 ha in 2016 and amounted to almost 70% of Canada's irrigated area.

Development and implementation of technologies related to rehabilitation of water supply infrastructure and on-farm irrigation within the irrigation districts have resulted in significant water savings by reducing distribution losses (seepage, evaporation) and improvements in on-farm water use efficiency and productivity. Salinity and waterlogging, which affected about 20% of the irrigated area throughout the irrigation districts in the 1970s, were essentially eliminated because of the irrigation rehabilitation program and improvements in on-farm irrigation technologies.

Figure 4.6 Low pressure drop tube pivot

Figure 4.7 Pipeline installation

Rehabilitation measures adopted were as follows:

(a) Replacing Surface Canals with the Underground pipeline - Surface canals were replaced with buried polyvinyl chloride (PVC). It was carried out in about 4,100 km (54%) of the 7,600 km of irrigation district-owned water distribution systems. These pipelines eliminated seepage, evaporation, and operational spills; reduced soil salinity and waterlogging on adjacent lands; improved water distribution efficiency and water delivery effectiveness for irrigation producers; and freed valuable land for irrigation development.

(b) Surface Canal Rehabilitation - The rehabilitation of surface canals was focused on the larger canals, which cannot be replaced with underground pipelines. Priority was given to canals where seepage was a problem. Rehabilitated canals were designed to optimize water delivery effectiveness and incorporate armor on the canal banks to protect against erosion. A buried plastic membrane was installed in the canal bottom and banks to prevent seepage losses. Automation and remote flow control of water in the canals continued to be an integral part of the irrigation rehabilitation program. This included pump control, reservoir control, upstream level control, downstream flow control, and water ordering by irrigation producers.

Figure 4.8 Automated check/drop structure

Figure 4.9 Unrehabilitated (a) and (b) rehabilitated canal

(a) On-Farm Irrigation Technology Improvements - Newer irrigation technologies, such as low-pressure drop-tube pivot systems and the production of higher-value speciality irrigation crops, were introduced. About 76% of the on-farm irrigation in the districts was carried out using low-pressure, drop-tube pivot irrigation systems with an efficiency rating of about 84%.

(b) Irrigation Demand Model - The Irrigation Demand Model (IDM), developed in 2002, enabled irrigation districts to assess long-term water supplies relative to expected irrigation demand accurately. This informed water allocation and expansion decision-making ensured equitable water sharing for all the irrigation producers and other water users. The IDM determines the on-farm water demand for each irrigated parcel of land within each irrigation district, using historical and current weather data and annually updated cropping and on-farm irrigation system data. The model links this data with the irrigation district water distribution Network Management Module, which is then used to estimate conveyance losses (return flow, evaporation, and seepage). The IDM was updated in 2017, enabling an even more accurate assessment of ongoing water demand within the irrigation districts.

(c) Alberta Irrigation Management Model (AIMM) - This decision support software package helped in informed irrigation scheduling. The software acquires the necessary climate parameters required to calculate evapotranspiration and irrigation recommendations from a comprehensive network of automated weather stations located throughout the irrigation districts. Producers can choose the closest weather station for their information requirements.

Until 2012, improvements to the irrigation conveyance infrastructure resulted in annual water savings of about 50 MCM. In addition, advances in sprinkler irrigation technology resulted in significant improvements in on-farm irrigation efficiency, which increased from about 35% in 1965 to about 78% in 2012. Based on a 10%

chance of exceedance, this reduced the mean on-farm irrigation demand from about 474 mm in 1999 to about 419 mm in 2012. On-farm irrigation efficiency is expected to increase to 85% by 2025. By 2012, changes in irrigation systems and water conveyance infrastructure reduced the gross demand by 74 mm, which included a 55 mm reduction in on-farm demand and a 19 mm decrease in conveyance losses, at a 10% chance of exceedance. During this period, rehabilitation of the canal distribution infrastructure, combined with improvements in the on-farm irrigation systems, reduced annual gross irrigation demand by 170 to 200 MCM, even including about 30,300 ha of irrigation districts' expansion during that time.

Implementation of a cost-shared funding program, specifically for the rehabilitation and upgrading of existing irrigation water supply infrastructure, was initiated in 1969. With the introduction of PVC pipe technology in the early 1980s, the program's focus shifted to the replacement of surface canals with underground pipelines. Total pipeline installation within the 13 irrigation districts averaged about 105 km/year from 1999 to 2012 and represented almost 90% of the total annual rehabilitation work carried out by the irrigation districts.

Irrigation districts authorized a further expansion of about 0.612 Mha because of improved water savings from the newly developed water supply infrastructure; and automated water conveyance systems. This expansion represents an increase in the irrigated area by about 57,000 ha from 2012 levels and about 34,000 ha from 2016 levels. Furthermore, Irrigation producers were expected to upgrade to more efficient irrigation systems on an additional 160,000 ha of land to reduce energy and labour costs, increase water use efficiency, and improve management of available irrigation water for higher value crop production. Increasing use of higher efficiency sprinkler nozzles and variable-rate irrigation technologies by irrigation producers on low-pressure centre pivot irrigation systems also enhanced on-farm efficiency gains. Irrigation districts continue replacing surface canals with underground pipelines wherever possible and rehabilitation of an additional 1,600 km of un-rehabilitated surface water conveyance infrastructure.

4.3 CHINA

4.3.1 Promoting Water-Saving Interventions in Large Irrigation Systems

Submitted By: Prof. Wang Aiguo (2017)

To build water-saving irrigation systems for efficient and sustainable utilization of water resources, revolutionary policies for planning and implementing water-saving irrigation projects, promoting the modernized transformation of irrigation schemes, enhancing awareness, and extending water-saving irrigation technology were implemented in China. As a part of the policy implementation, the construction of auxiliary facilities, up-gradation of existing equipment, and water-saving irrigation technologies demonstrations were organised in different districts.

Working out policies on promoting the development of water-saving irrigation: The policy draft document was accepted by the Government and included in the Outline of the National Agricultural Water Conservation Program (2012 - 2020). It was implemented as one of the key national policy areas for efficient and sustainable water management. Enterprises, village-level organizations, and individuals were encouraged to invest in water-saving facilities with financial subsidies from the government to purchase the requisite equipment. Additionally, Regulations for Irrigation and Drainage were composed to improve the comprehensive agricultural production capacity and to ensure national food security. The regulations were put into force in 2016 in China.

Working out plans for water-saving irrigation development: National plans were formulated for developing modern irrigation, building auxiliary facilities, transformation projects in large and medium-sized irrigation schemes, water-saving irrigation in pastureland, upgrading large-scale pump stations, and the implementation strategies for saving water and increasing grain output in four provinces and autonomous regions in northeast China. They also restricted the over-extraction of groundwater to develop highly efficient water-saving irrigation in North and South China. These plans laid the foundation for the national water-saving irrigation development strategy, management, and investment.

Promoting investment in water-saving irrigation projects by Central Government: Discussions were held to increase Central Government's investment in water-saving irrigation projects. The Central Government allocated 30 to 50 billion RMB annually to develop water-saving irrigation projects, focusing on the transformation of large and medium-sized irrigation schemes, large-scale development of efficient water-saving irrigation on the farm, and upgrading large-scale pump stations for irrigation or drainage. Along with adopting advanced agro-techniques and agricultural mechanization, such as laser control levelling equipment, comprehensive grain production capacity and efficient water resource utilization were also promoted, creating the base for modern agriculture.

With the implementation of these plans and policies, the water-saving irrigation area in China increased by 10.2 Mha, irrigation water application quota per hectare reduced from 5,910 m^3 to 5,610 m^3, irrigation water use efficiency increased from 47.6% to 53.6%, and water use efficiency increased by 12.6 %. Each year about 3,060 MCM of water is saved due to the development of water-saving irrigation in China. At present, there are more than 2,000 specialized manufacturers in China, whose water-saving equipment can annually irrigate more than 2 Mha.

To promote large-scale and integrated development with distinctive regional characteristics, efforts were made to construct the national demonstration counties for efficient water-saving irrigation across the country. To assess the effectiveness of the national demonstration counties, six national demonstration counties were selected for assessment.

Technical training programs were also organised for different regions and levels. The main topics of the training were technology and application management of sprinkling irrigation, micro-irrigation, and pressurized water supply technology, IT application in irrigation schemes, calculation, and analysis of the water use efficiency in irrigation, and management of water-saving irrigation projects. Efforts were also made to limit the irrigation quota management and monitor the total water used for irrigation. Water use cooperation associations were promoted among the farmers to upgrade water management at the farm level. Comprehensive reform on agricultural water prices was launched, and a specialized user service system in water-saving irrigation was established. To tackle the water shortage problem, the government targeted expanding water-saving irrigation area by 1.33 Mha every year and to reach 55% of water use efficiency in China by 2030. These targets were to be achieved by implementing the National Water Conservation Program, incorporating water-saving indicators, and modernising the irrigation schemes.

4.3.2 Jiamakou Irrigation Scheme (JIS)

Submitted By: Mr. Zhang Xuehui (2013)

The Jiamakou Irrigation Scheme (JIS) was constructed from July 1958 to July 960, and it is the first large high-lift irrigation scheme in the Yellow River Basin in China. After nearly 40 years of operation and noticeable wear and tear, some problems emerged, such as outdated facilities, obsolete infrastructure, overstaffing, organizational overlapping, and old-school management.

In 1998, the scheme was revived, the pumping stations and irrigation canals were rehabilitated to provide better services. The rehabilitation and reform innovations in JIS were extended in 10 large irrigation schemes in Shanxi Province, three large irrigation schemes in Gansu Province, and two large irrigation schemes in Henan Province of China. The reforms covered an area of 6,45,000 ha, and 630 MCM water was saved in three years.

The reform and innovations were implemented gradually in the irrigation scheme. First of all, the infrastructure and facilities of the scheme were upgraded for enhancing the system capacity for water supply, delivery, measurement, and control. Secondly, management system reforms were introduced to strengthen the operation and maintenance of the system. Benchmarking was also adopted to evaluate the progress. The monitoring and analytical results indicated that water use efficiency, water productivity, and sustainability of the JIS system had improved significantly.

The Geographic Information System, water measurement techniques, digital and image technologies were integrated into irrigation water management information system. Technical improvements were conducted to increase the operational duration of the pump. It led to an increased 2,630 hours of operation, reduced annual maintenance cost up to 10% of the original cost, and the service life of the impeller jumped from 1,000 hours to 4,000 hours. Cast-in-place U-type concrete section and arc-bottom trapezoidal section were used in the main canal, the largest cast-in-place concrete canal in China with a discharge of 30.5 m^3/s. It has a strong frost resistance, a low roughness coefficient, a high flow rate, and a good sediment transport capacity. In 2001, a floating pumping station was designed which could accommodate the fluctuating water level of the Yellow River.

An integrated and scientific irrigation management system, which included human resources management, water supply management, water-entity management, assets management, financial management, information management, and technological advancements, was implemented, and it proved successful. With these reforms, the efficiency of JIS improved remarkably. The establishment of WUAs strengthened the tertiary canal management facilitated farmers' participation in the system’s maintenance and decision-making.

Water-saving: The water use efficiency at the main and branch canals increased from 0.68 in 1996 to 0.83 in 2012. More than 18 MCM water was saved every year, and about 120 MCM of water was saved from 2000 to 2012.

Increased revenue: The annual added value of irrigation water increased from 570 million RMB Yuan to 1,730 million RMB Yuan and added value of per cubic meter of irrigation water in the JIS increased from 10.62 RMB Yuan to 22.34 RMB Yuan. During the same period, the annual net income per farmer increased from 5,040 RMB Yuan to 14,100 RMB Yuan.

Increased irrigated area: The irrigated area increased from 12,333 ha in 1998 to 33,530 ha in 2007. With the north extension project in 2008, the irrigated area increased to 60,600 ha in 2012.

Increased staff income: The annual average income of each staff member increased from 3,300 RMB Yuan in 1998 to 35,263 RMB Yuan in 2012.

Social benefits: FAO's 2006 five-day assessment of the irrigated area stated, *"The overall irrigation benefits, water use efficiency and irrigation water productivity are all higher, compared with other irrigated areas with the same conditions and lead the way in China and the Asia-Pacific region"*

The innovations and experiences in JIS have been summarized and replicated in other irrigation schemes. In the JIS operation, three primary elements of the water supply were reformed, known as the "three flows": the commodity (water) flow, the capital (water fee) flow, and the information (water information) flow. The same model and concept can be followed in similar large projects.

4.4 EGYPT

4.4.1 Crop Rotation: An Approach to Save Irrigation Water under Water Scarcity In Egypt

Submitted By: Prof. Samiha Ouda and Abd Hafeez Zohry (2015)

Feeding a population growing at an annual rate of 1.84% with limited land and water resources is the most important challenge for Egypt today. There is a large gap between the production of all strategic crops and their consumption. More than 85% of the water withdrawal from the Nile is used for irrigated agriculture. Water availability, therefore, has a direct influence on national food security. Surface irrigation is used on over 80% of Egypt's cultivated land. Poor water management is contributing to irrigation water wastage.

Figure 4.10 Wuwang floating pumping station

Figure 4.11 The "three flows" in supplying water

Previous research demonstrated improved agricultural management practices such as raised bed cultivation could save a good percentage of irrigation water, enhance the environment for growing crops, increase the yield, and positively impact the farmer's net revenue. Crop rotation was touted as one such technique that can save applied irrigation water in various crops with medium to low water requirements. Using crop rotations further helped in the sustainable use of natural agricultural resources and increased agricultural productivity under the prevailing conditions of water scarcity.

In South Egypt, the cropping choices in the old land, new land, and salt-affected lands (sandy and calcareous soils), in addition to sugarcane cultivation, consume a high amount of irrigation water and fertilizers. Therefore, crop rotation was implemented in each of the above locations. These rotations were characterized by cultivating on raised beds, saving about 20% of the applied surface irrigation water. Furthermore, high water-requirement crops were replaced with water-extensive crops during these rotations.

Finally, intercropping was practised; two crops were cultivated on the same unit of land using the same amount of applied irrigation water. In the old land, with proposed rotations, the saved irrigation water varied from 1,095 to 1,331 m^3/ha, while 1,546 m^3/ha was saved in Lower, Middle, and Upper Egypt, respectively. On the other hand, in calcareous soil 3,160 m^3/ha could be saved with the proposed rotations. However, in sandy soil a low amount of water was saved – 53, 67, and 152 m^3/ha in Lower, Middle, and Upper Egypt, respectively. In salt-affected soil, 3,426 m^3/ha was saved. The irrigation water saved under sugarcane rotations was 3,596 and 7,609 m^3/ha for spring and autumn rotations.

The second step was to validate the results of these experiments by replicating them in different locations. Demonstration experiments were conducted, and these field days and harvest days were attended by the farmers from the surrounding areas. After that, farmers adopted these innovative techniques under the supervision of the Central Extension Administration workers.

Crop rotation in conjunction with intercropping solved the food insecurity problem by increasing water and land productivity. Climate change is expected to negatively affect water resources in Egypt in the future, worsening the existing situation further. Therefore, the urgency to adopt unconventional procedures to increase crop production and maintain irrigation water is greater today than ever.

4.4.2 Improving Growth, Yield, and Water Productivity of Maize Cultivars by New Planting Method

Submitted By: Dr. Yosri Ibrahim Mohamed Atta (2014)

Maize is one of Egypt's most important cereal crops, sown as a summer crop for human consumption, animal feeding, and industrial purposes, specifically for oil and starch production. Due to the production deficit, efforts are made to increase the productivity of the cultivated area by using high-yielding seeds, improving agronomic practices, and optimizing water use. Using the right amount of water at the right time in the irrigation cycle is pertinent to establishing good water management practices in line with the strategy of irrigation policy in Egypt. The innovation presented here is a new planting method with surface irrigation technique to increase the irrigation application efficiency, water-saving, field water use efficiency, and improved quality and quantity of the yield.

In this method, the irrigated area was divided into furrows. The top furrow was named Border, the bottom one was named Tape, and the combination of one border and tape was called Strip. Grains were planted in the bottommost furrow using the same plant density as recommended in one or two rows of plants according to strip width. Sufficient irrigation water was provided to reach the saturation for top furrows depending on the dimension of the strip. Then the next batch of irrigation water was provided for only tapes in addition to small portions on both the sides of furrows as a result of water flow in these tapes. Accordingly, the wet area of the strip was less, and consequently, water-saving increased by about 30-50% or more without compromising the yield.

The conventional farming technique was termed Treatment A. Two newer treatments were evaluated during the irrigation cycle.

Treatment B: Planting on a strip of furrows with 80 cm width (bottom of furrows) following the width of the traditional furrow, with one row of plants of 22 cm in between. Grains were planted in the bottom of the furrows using the traditional plant density method.

Treatment C: Planting on a strip of furrows with 160 cm width with one row of plants of 22 cm in between. Grains were planted in the bottoms of furrows using the traditional plant density.

The amounts of irrigation water applied for each treatment group during growing seasons were measured by a calibrated flow meter (in m^3) for each irrigation cycle. Irrigation water was transmitted to each plot through polyethylene pipes of 6-inch diameter, and there was a valve in front of each plot to control the water distribution. The maize plant received seven irrigation cycles throughout the growing season, including planting irrigation. Equal amounts were provided for all treatment groups until soil saturation (peddling) was achieved for all areas. Life or first irrigation was started after 21 days from planting, and then the irrigation interval was 14 days each. After 90 and 95 days from planting, the irrigation was stopped.

It was found that the amount of applied water was the highest for treatment A which recorded a maximum value of 8,143 m^3/ha. On the other hand, the lowest value of 3,810 m^3/ha was obtained from the strip of the furrow with 160 cm (treatment C), while treatment B recorded 5,676 m^3/ha. The water applied and water productivity data (WP = Grain yield (kg/ha)/water applied (m^3/ha)) revealed that treatments B and C saved around 30.4-53.22% of applied irrigation water, respectively, compared to treatment A. Treatment group C had the highest value of WP (1.78 kg/m^3) followed by treatment B which was 1.17 kg/m^3, while treatment A recorded the lowest value of 0.77 kg/m^3. Concerning grain yield. it was noticed that the decrease in grain yield in treatment A might be due to the excess of applied water, which led to partial aeration deficiency in the upper part of the root zone. Also, the excess wetting of the top of the furrow may have resulted in leaching out of some nutrients from the root zone. The slight increase in grains yield (6.18%) for treatment B was due to the increased plants. This was also true for treatment C. In terms of economic evaluation, it was found that treatment C had the highest value of net profit because of low irrigation and labour costs. On the other hand, it gave the highest value of grain yield resulting in economic efficiency for capital investment and investment ratio compared to the other treatments.

In the 2010-2011 growing seasons, the innovation demonstrated positive results in two different sizes of cultivable areas in water-saving, increased water productivity, and overall economic benefits. By controlling the application and the timing of irrigation water in an appropriate planting setting, the amount of labour was also reduced, thus creating the possibility of employing these resources in further extension of the irrigation area.

4.4.3 Water Management for Maize Grown in Sandy Soil under Climate Change Conditions

Submitted By: Ahmed Mohamed Taha Abeid-Alla (2013)

Agricultural management practices were improvised for efficient irrigation of maize and wheat in sandy soils in Egypt. The research was applied on a 1 ha land at the farm level and later expanded to 10 ha in the *Bustan* area in *El-Behira* Governorate. Techniques like drip irrigation and fertigation in line with regional climate conditions were implemented, which enhanced the yield.

Eight fertigation treatments in addition to farmer irrigation (control treatment) were tested. Two climate change scenarios obtained from the Hadley climate change model were incorporated in CropSyst model to assess maize yield responses to fertigation regimes under the climate change conditions.

It was observed that under appropriate climate conditions, applying irrigation using 1.2 ETc (Evapotranspiration) saved 28% of irrigation water and increased maize yield by 10%, compared to the yield obtained by the traditional technique. The results can be summarized as follows:

(a) Irrigation treatment 1.2 ETc (irrigation every three days) and fertiliser application in 80% of irrigation time gave a higher yield of maize. Compared to the farmer treatment, the productivity reached 6.67 tons/ha as an average of the two growing seasons.

(b) Irrigation treatment 0.8 ETc and fertiliser application in 80% of irrigation time gave the highest productivity of irrigation water (15.65 kg/mm) and water use efficiency (27.96 kg/mm) as an average of the two growing seasons. Therefore, this treatment was recommended due to the water scarcity conditions in Egypt.

(c) The highest maize yield reduction (45%) was obtained from irrigation using an amount of 0.6 ETc and application of fertilizers in 60% of the application time. The lowest yield reduction was obtained from irrigation using 1.2 ETc, i.e., 37 and 39% in the first and second seasons. Under an ideal climate change scenario, the yield reduction was between 34 to 35% for the first and second growing seasons.

(d) To reduce climate change risks and increase water productivity, maize was irrigated with 120% ETc and the fertilizer was applied in 80% of irrigation time in sandy soils under drip irrigation system.

(e) The highest water productivity of 16.44 kg/mm was obtained under the treatment of 0.8 ETc and fertilizer application at 80% of irrigation time in two growing seasons. The lowest value of water applied under the farmer treatment of the surrounding area was 10.14 kg/mm.

(f) Growing maize crop under the 1.2 ETc irrigation treatment and applying fertilizers in 80% of irrigation time saved 27% of irrigation water and increased grain yield by 11% in the first and second growing seasons, respectively, compared with farmer treatment.

These customized techniques can be replicated in other parts of the region, saving water, increasing yield, and enhancing the local economy.

4.4.4 The Exchangeable Effect of Deficit Irrigation and Planting Methods on Enhancing Irrigation Water Productivity of Rice

Submitted By: Mahmoud Mohamed Abdalla Mahmoud (2013)

A new planting management method for producing more rice with less water was developed in the northern Nile Delta of Egypt. A higher quantity of rice was produced with less water by using a new furrow-based planting technique through transplanting in the bottom of wide furrows (beds). Moreover, deficit irrigation techniques and treatments were also tested and evaluated. Both techniques proved to save irrigation water.

Field experiments were conducted in 2009 and 2010 at *Sakha* Agriculture Research Station, Kafr El-Sheikh, Egypt, to study the effects of deficit irrigation and planting methods on the productivity of rice irrigation. The experiment was designed as a split-plot design with four replicates. Rice planting methods were used in the main plot, while deficit irrigation was allocated to the sub-plot. Planting methods followed traditional transplanting in flooded soil with furrows and beds only.

Deficit irrigation treatments were:

1. Irrigation every six days after transplanting
2. Irrigation every six days with two skips: 54 and 60 days after transplanting
3. Irrigation every six days with two skips: 42 and 54 days after transplanting
4. Irrigation every six days with three skips: 42, 54, and 66 days after transplanting

After the experiments, it was realized that irrigation water applied to rice fields could be significantly reduced without sacrificing yields or increasing production costs by using deficit irrigation (1), i.e., irrigation every six days after transplanting in the beds only. Deficit irrigation in rice should be applied in non-critical stages, especially in a period that is not more than six consecutive days. Transplanting at the bottom of beds technique increased the productivity of irrigation water by 46% and 33% compared to traditional transplanting and furrow transplanting methods, respectively.

Therefore, transplanting in the beds could only be used by the farmers under the deficit irrigation (1) because it increased the productivity of irrigation water by 45% and saved water by 34%. The main outcomes of the research were shared at national events, and demonstration trials were held under the supervision of the Central Administration of Agriculture. To promote the adoption and build local capacities, dissemination material was developed for farmers' training and extension programs at the field and the scheme levels.

4.4.5 Innovative Method for Rice Irrigation with High Potential of Water Saving

Submitted By: Dr. Yousri Ibrahim Atta (2008)

Rice is a staple food crop and is more profitable than other summer crops such as maize and cotton; it is also one of Egypt's most water-consuming crops, usually grown under submerged conditions. Although the authorities in Egypt limited the area devoted to rise to around 46,000 ha/year, farmers grew it due to its high profitability. Consequently, the pressure increased on the limited resources and caused water shortages during the peak summer season.

One strategy was devised to combat water scarcity in the form of a new planting and irrigation method with a high potential for water-saving. This planting and irrigation technique reduced irrigated areas by dividing the land into furrows. The top of the furrow was named (border), and the bottom of the furrow was named (tape) to form a “strip”. According to strip width, the seedlings were transplanted in the tape with the same plant density as recommended in two rows of plants. Planting irrigation was provided with enough irrigation water for reaching the puddling time; then, the next irrigation was given for taps only with a depth of 7-cm. Accordingly, flooding area was less and consequently increased water-saving by about 40%.

In addition, it decreased percolation losses and reduced evaporation. This method of rice cultivation (on strips) was applied on 150 ha of farmers’ fields on five governorates under different soil and climate conditions. This method aimed to seek the possibility of growing rice in strips to increase the water use efficiency of rice cultivation with a cropping period of 135 days.

The technique had a significant effect on the grain yield. The highest grain yield (9.28 tons/ha) was obtained from transplanting in strips of furrows of 80 cm width (M2), while the lowest value was recorded from traditional transplanting on the flat at the hills (M1) (8.79 tons/ha). The amount of water used for land preparation, for both nursery and permanent field, and raising for 30 days and through 7 days after transplanting and before treatments application were on an average 4,019 m^3/ha. The nursery area was about 1/10th of the permanent field area. Water use through treatment application was on average 10,941 and 5,003 m^3/ha for M1 and M2 treatments, respectively. According to the different planting methods, the total water used by rice was 14,960 and 9,023 m^3/ha for M1 and M2 treatments, respectively. The water saved was about 5,937 m^3/ha (39.69 %), and the yield increased by 5.86 % for M2 treatment. The highest water use efficiency (WUE) was recorded for M2 treatment (1.03 kg/m^3) while the lowest one was recorded for M1 treatment (0.59 kg/m^3). The net return for rice cultivated under the strip method (M2) was calculated at 0.18 USD /m^3 of water compared to 0.09 USD/m^3 of water for rice cultivated under the normal method (M1). On the other hand, the benefit-cost ratio (B/C) for rice (M2) was higher than that for rice (M1).

This technique was used in 2002 in a small research area as an experimental work. After that, between 2003 till 2005, it was implemented in different governorates covering all climate and soil conditions in Egypt due to positive results. This extension work was aimed to spread awareness about water-saving among the farmers. The extension work’s cultivated area was 50 ha distributed on different sites. Subsequently, in 2006 and 2007, it was replicated on large scales in five regions, including Fayoum Governorate, Middle Egypt, on cultivation area of about 150 ha. Based on the project’s success, it was estimated that if applied in all the rice-growing fields of Egypt, about 3.7 MCM of irrigation water could have been saved.

Figure 4.12 Furrow based rice cultivation

The innovation is an excellent example of the lab to field research extension. The government's support also helped take the research to the field for implementation. The benefits of this approach have successfully enabled farmers to adopt the new planting technology and increase productivity for more financial gains meanwhile regulating the use of water and land resources.

4.4.6 Smart Management for Saving Water and Producing More Crops with Less Water

Submitted By: Prof. Dr. Alaa Zoheir El-Bably and Prof. Dr. Sayed Ahmed Abd El-Hafez (2018)

In Egypt, wheat is sown through the traditional broadcasting method on a large area under flood irrigation. It requires a higher seeding rate at about 167 kg/ha, and a large quantity of irrigation water yet gives a low yield and yield components.

In this management technique, a simple and effective method called Raised beds (RB) furrows planting was initially implemented in wheat production and was later expanded to rice, maize, cotton, and soybean cultivation. It led to increased grain yield, improved water productivity, and saved the applied irrigation water compared to the traditional flat method.

Two fields were created, one with the conventional broadcasting method on a large area under flood irrigation. The second one was prepared using the raised beds furrows. Furrows were made with different widths according to crops and soil types. The widths of raised beds were different from 80 cm (narrow beds), 100 cm (medium beds) to 120 cm or more (wide beds). Seeds were planted on top of the beds (rows, hills, or broadcasting) according to requisite raised beds widths.

Figure 4.13 Conventional method versus Raised beds furrows

Several experiments were also conducted on rice and maize production using the strips method over the years, starting from 2003. Between 2003-2005, the effect of different raised bed widths, seeds distribution, and water-saving was studied. It was concluded that wheat cultivated on raised beds width of 100 cm saves about 21% of irrigation water and increases the grain and straw yield.

Water consumed in the traditional planting method for wheat production was 6,023 m^3/ha compared to 4,626 m^3/ha consumed in the raised beds furrows methods (width 120 cm). The raised beds of furrows with width 100 cm recorded 4,726 m^3/ha and furrows with width 80 cm recorded 4,988 m^3/ha water consumption, respectively. This accounted for water-saving of 17.18 % for 80 cm width raised beds, 21.53 % for 100 cm width raised beds, and 21.53 % for 120 cm width raised beds. This method was also used to cultivate cotton, rice, corn, and soybean, and it increased yield and other advantages.

Given the method's advantages and the assured regularity of plant growth, some farmers raised furrow beds for vegetables and intercropping patterns (wheat-cotton). Increased yield, lower costs, and water-saving were seen in all cases. This management technique can be easily implemented in other parts of the world.

4.4.7 Lake Nasser Evaporation Reduction Study

Submitted By: Sherine Shawky Ismail (2012)

Lake Nasser is one of the largest artificial freshwater reservoirs in the world. It was formed due to the construction of the Aswan High Dam during the 1960s in Egypt. It is an elongated body of water about 500 km long, upstream from the dam, about 170 km of which is in Sudan, called Lake *Nubia*. One of the emerging challenges today is the evaporation losses from Lake Nasser. The evaporated water loss ranges between 10 and 16 BCM every year, equivalent to 20–30% of the Egyptian income from Nile water.

Given the situation, an evaporation reduction study focused on closing the secondary channels to control evaporation. It was found that closing only a few strategically selected secondary channels (*khors*) out of the existing hundred channels can reduce the environmental impacts. In addition, both the partial and the complete closing of the secondary channels were considered to eliminate all the environmental impacts. These secondary channels are also the nesting ground for many fish species and other animals such as crocodiles and birds. Some communities and small industries are also located on these secondary channels. The environmental impacts were carefully considered as part of the study for these reasons.

This evaluation study integrated remote sensing, Geographic Information System (GIS) techniques, aerodynamic principles, and Landsat7 ETM+ images. Three main procedures were carried out in this study; the first derived the surface temperature from Landsat thermal band; the second derived evaporation depth and approximate evaporation volume for the entire lake, and quantified evaporation loss to the secondary channels' level over one month by applying aerodynamic principles on the surface temperature of the raster data. The third procedure applied GIS suitability analysis to determine which secondary channels should be disconnected.

The results showed evaporation depth ranging from 2.73 mm/day at the middle of the lake to 9.58 mm/day at the edge. The evaporated water-loss value throughout the lake was about 0.86 BCM/month. The analysis suggested that an approximate total evaporation volume loss of 19.7 MCM/month (in March), and thus 2.4 BCM/year, can be saved by disconnecting two *khors* with approximate construction heights of 8 m and 15 m. Evaporation depth in mm/day reached maximum values near secondary channels due to proximity to land where the temperature is higher.

It was clear that there is a strong correlation (R^2 = 0.98, coefficient of determination) between surface temperature and evaporation depth in mm/day. It was concluded that the evaporation loss could be reduced, and the lake's water can be saved by disconnecting some secondary channels where the evaporation losses are higher. ArcGIS suitability analysis was applied to select the most suitable secondary water channels to be disconnected.

However, more research is needed to continue this inquiry and form a database for lake evaporation metrics and the potential impacts of disconnecting various *khors*. The proposed idea was considered by the Ministry of Water Resources and Irrigation to study its impacts and required social and environmental mitigation for the application.

4.4.8 Soil and Soil-less Cultivation Using Constructed Wetlands Treated Drainage Water

Submitted By: Ahmed Ali Rashed (2016)

In the absence of any water source other than brackish drainage water and no land for agricultural production other than wetlands, Lake Manzala (LM) basin in Egypt needed to identify water for agricultural production. A unique approach was followed to overcome the issue. Wetlands were constructed to treat brackish drainage water, which reclaimed the saline-sodic soil and led to vegetable production on rice bales as an alternate growing media. The approach was later called the El-Salaam Canal project, a successful project that reclaimed saline lands by applying mixed drainage water with fresh Nile water (EC = 1-1.5 dS/m) in North-eastern Nile Delta. Within 20 years (1995-2015), 500,000 acres (202,343 ha) were added to the Egyptian croplands after reducing their salinity and toxicity.

Two demonstration farms (DF) located on LM fringes were prepared. The first had a waterlogged saline-sodic soil, electrical conductivity (EC_e) of 47-73 dS/m, and exchangeable sodium percentage (ESP) of 60-88%. In contrast, the second farm had rice bales placed on top of such soil to act as an alternate cultivation media for vegetable production. The salinity of irrigation water (EC) was in the range of 5.4 and 8 dS/m.

Land reclamation continued for five years, starting with land levelling, salts leaching, cultivation of salt-tolerant grasses followed by salt-tolerant crops (fodder beets then sugar beets). Rice bales were arranged in rows, equipped with a drip irrigation system, and were initially irrigated for one month for composting. The bales were cultivated during 2015-2016 with vegetables like tomato, eggplant, and chilli pepper in summer, followed by onions and cabbages during winter.

Treated water application provided an alternative water source; local wastewater was reused instead of importing freshwater from far away catchments. The good quality water was then used for new land and crop expansion projects. Landowners, fishermen, and farmers accepted the idea, reclaimed their fallow lands, and produced vegetables on rice bales media.

Within five years, using treated brackish drainage water, salinity and infiltration rate improved significantly, especially at the topsoil (0.5 m depth). The crop yields of produced fodder and sugar beets were 52% and 70% of the Delta beets yield, which was economically acceptable. Bale-media yields were 30.0, 23.3, 6.67, 37, and 13 ton/ha for tomato, eggplant chilli pepper, onions, and cabbages, respectively, almost equivalent to the average production of fertile soils irrigated with fresh Nile water.

An economic evaluation of the two demonstration farms indicated that the rice bale cultivation gave early net income gains ranging from 35 to 3,230 USD/ha compared to the almost positive income (200 -500 USD/ha) obtained after five years of continuous reclaiming of the adjacent farm.

Rice bale cultivation managed to reduce the overall costs and save time and water. The water consumption per kg of produced rice bale cultivated tomato, eggplant, and chilli pepper were 0.05, 0.06, and 0.22 m^3/kg compared to the 0.32 m^3/kg of the reclaimed lands sugar beets.

Furthermore, the fishermen community at the LM fringes imitated the technique and reclaimed their lands by cultivating vegetables on rice bales using a small portion of the treated water. They developed their lifestyle by producing and marketing high-value vegetables and cash crops. It also helped save the environment from rice straw burning and maximizing its value.

Egypt has five northern lakes (*Manzala, Burullus, Idko, Mariut, and Bardaweel*). These lakes receive agricultural water loaded with nutrients, salts, and biological contaminations. The estimated land irrigated by these lakes is 15,000 ha with waterlogged saline-sodic soils. This technique of using rice bales as wetlands to treat drainage water in crop production can be replicated in such regions. The excess drainage currently dropped at the northern lakes is nearly 13 BCM/year. Only 3% of such water is sufficient to reclaim the available 15,000 ha saline area surrounding the Egyptian lakes.

4.4.9 Assessment of Deficit Irrigation on Wheat and Maize Water Productivity in Sandy Soils

Submitted By: Mr. Ahmed M. Taha (2015)

Agricultural water demand is one of the pressing challenges worldwide, and Egypt is no exception. Almost 85% of the country's total available water is consumed in agriculture, and most of the on-farm irrigation systems are low in efficiency, coupled with poor irrigation management. In such circumstances, understanding, measuring, and assessing water flows around the farm, along with appropriate farming practices, became important. Wheat (winter crop) and maize (summer crop) are two important crops in Egypt cultivated on the sandy soil of *El-Bustan, El-Behira* governorate. The productivity of these two crops is usually lower than their counterparts from old, cultivated land in Egypt for several reasons. Excessive water applications characterize farming practices regarding water and fertilizer use.

However, the crops' productivity can be enhanced by using improved agricultural management practices that boost the growth environment and increase final yield. Following this, research was conducted where wheat and maize were cultivated with drip and deficit irrigation and constant water consumption monitoring. Initially, the research was applied in a 2-ha land and was further applied at individual farmers' level on 1,680 ha for wheat and 1,450 ha maize.

Efficient agriculture is the achievement of the highest yield per unit land surface. In recent years, it was realized that such a goal entails a wasteful use of water resources, and the principles of deficit irrigation were developed. Although the water use was rational, deficit irrigation reduced the yield level to some extent. Nonetheless, with due precautions, the research was implemented using deficit irrigation to avoid water stress in sensitive growth stages and prevent high yield losses.

Two field experiments were conducted on wheat and maize crops at *Aly Mobarak* experimental farm in the South Tahrir Research Station, Egypt (30 28 E and 31 02 N, 6.7.m above sea level). Five irrigation treatments (120%, 100%, 80%, 60% evapotranspiration ETc, and farmer practice) and two fertigation treatments (adding fertilizer in 80% and 60% of irrigation time) were tested. The experiment was conducted for wheat crops using the sprinkler irrigation system. For maize crops, the experiment was conducted using the drip irrigation system. The soil at the experimental area was sandy texture with an average bulk density of 1.67 Mg/m^3 and was alkaline in reaction with a pH value of 7.70. The average soil electrical conductivity measured in the soil saturated paste extract was about 0.35 dS/m. For irrigation water, the electrical conductivity was 0.50 dS/m, and the pH value was 7.62.

It was concluded that applying deficit irrigation up to 80% ET_c with fertiliser application in 80% of irrigation time does not affect wheat grain yield, saves irrigation water, and increases water productivity in sandy soils.

For wheat, the grain yield increased by 44%, and 27%, the applied water was saved on an average over the two growing seasons, compared with farmer irrigation practice. Furthermore, deficit irrigation for wheat reduced yield by 2% on average for two seasons and saved 11% of the applied water. The highest water productivity of wheat indicated a value of 1.76 and 1.49 kg/m^3 in the first and second growing seasons, respectively.

For maize, the 120% ETc treatment application increased maize grain yield by 14% and saved 28% of the applied water compared to farmer irrigation. Moreover, maize yield was reduced by 8% under deficit irrigation with 14% water-saving on an average of both seasons.

Farmer irrigation practice reduced water productivity compared to the other irrigation treatments. The lowest productivity values of 1.09 and 0.84 kg/m^3 of applied water were achieved under farmer practices in the first and second seasons. This could be attributed to the large irrigation water amounts used by the farmers that resulted in nitrogen fertilizer leaching away from the root zone, especially when the fertilizer was applied by broadcasting on the soil surface.

The highest productivity values of 1.74 and 1.49 kg/m^3 of applied water were obtained from irrigation with 100% ETc with fertigation in 80% of application time in the 2013 and 2014 seasons.

From a futuristic perspective, production packages including irrigation systems, amount of applied water, and fertilizer application technique should be provided to the farmers to improve the productivity of wheat and maize crops. There is a lot of scope for the technique's expansion since 90% of the newly reclaimed lands in Egypt are sandy soils. This can help save water, restrict fertiliser use, increase yield, and enhance farmers' income.

4.5 INDIA

4.5.1 Participatory Rainwater Conservation in Rainfed Agriculture

Submitted By: Prof. Dr. Subhash Madhawrao Taley (2011)

In *Vidharba* region of *Maharashtra*, a south-western state of India, around 93% (5 Mha) of the cultivated land is dependent on rainwater for crop production. Due to variable and uncertain rainfall in the monsoon season, crop yields are quite low and unstable. Rainfed agriculture supports about 65% of the rural population and is the major producer of cereals, pulses, and oilseeds. The farmers' community implemented participatory rainwater management in the region to manage this situation and increase water productivity.

To enhance crop productivity and reduce unstable crop yields during uneven rainfall, farmers used a participatory approach to adopt in-situ rainwater conservation practices. It enhanced soil moisture and captured the runoff water in farm ponds for irrigation during dry spells.

In-situ rainwater conservation consists of various rainwater conservation measures, including modified land configurations like deep cultivation, contour and across the slope cultivation, intercropping, and opening furrows (intermittently broken), among others. Farm pond storages were created, runoff harvested from the cultivated fields into the farm ponds was used to provide protective irrigation during a prolonged spell of rainfall in K*harif* (monsoon) and moisture stress in *Rabi* (winter) seasons.

In deep cultivation, the water use efficiency (kg/ha-mm) achieved was between 1.24 - 1.49 for soybean crops and 0.98 - 1.09 for cotton. Compared to shallow or conventional cultivation, the crop yields in deep cultivation were higher by 11% to 37%, runoff also decreased by 8% to 13%, and soil loss was reduced by 17% to 31%.

The opening of tide furrows in crops like cotton, soybean, black gram, green gram, and sorghum enhanced the yield levels by 4% to 14% and water use efficiency from 1.18 to 2.82 kg/ha-mm than the conventional field layout.

In the case of across the slope cultivation, higher crop yields up to 50% and water use efficiency of 0.55 - 2.67 kg/ha-mm were achieved. Similarly, in contour cultivation, the crop yields were higher by 39% to 88%, and the water use efficiency was achieved between 0.55 - 2.67 kg/ha-mm. Similarly, higher crop productivity and water use efficiency trends were observed in alternate furrows across the slope and in contour cultivation.

Square basins (20 m x 20 m) prepared before the commencement of rains enhanced the yield of chickpea by 67% and rainwater use efficiency in the range of 0.89 to 1.48 kg/ha-mm over the control trial. Green manuring of the basins during monsoon season enhanced the soil moisture content from 43% to 64%, increased yield of chickpea by 38%, and rainwater use efficiency from 0.89 to 1.22 kg/ha-mm over the control treatment.

The protective irrigation using the drip system enhanced the yield of pigeon pea by 67%, and water use efficiency was between 0.89 to 1.38 kg/ha-mm. Two protective irrigations through drip systems in cotton enhanced the yield level by 51% and water use efficiency between 1.61 to 2.13 kg/ha-mm. One protective irrigation in soybean through sprinkler system using farm pond storage enhanced the yield by 24% and water use efficiency from 2.15 to 3.48 kg/ha-mm over the controlled field treatment.

Participatory water management technique followed by 9,500 farmers from 115 villages in the region conserved an estimated 227 Mha of water on 21,000 ha land between 2009 and 2010. Furthermore, 50,000 m^3 of water was made available for protective irrigation by promoting the construction of 15,000 farm ponds, leading to a significant increase in crop yields.

Figure 4.14 Tied (intermittently broken) furrows in cotton

Figure 4.15 Sprinklers irrigation using farm pond water

Field experiences over the years showed that modified land configurations like deep cultivation, across the slope or contour cultivation, and opening of furrows and tied furrows, green manuring, square basin layout, enhances rainfall storage in the soil profile. Farm ponds provide irrigation water to crops during dry spells.

With an integrated effort from the government and the community, participatory practices can bring change, leading to social and economic benefits while increasing water productivity.

4.5.2 Transformation of Irrigation through Management Transfer User Groups

Submitted By: Messrs Shahaji Manikrao Somawanshi, Bharat Kawale and Sanjay Madhukar Belsare (2009)

The participatory Irrigation Management (PIM) approach was introduced in India in the 1990s. The Government of India has been promoting PIM in irrigation schemes to improve irrigation infrastructure operation and maintenance, reducing fiscal burden, increased cost recovery, and higher crop production through better water management. As a result, more than 50,00 Water User Associations (WUA) were formed all over the country. *Waghad* Irrigation Scheme in *Maharashtra* is one such example that created an impact.

Waghad Irrigation Scheme, located in *Nashik* district of *Maharashtra* in India, was commissioned in 1981. The scheme's cultivable command area was 9,642 ha, but only one-third (3,212 ha) was irrigated as farmers in tail areas were deprived of irrigation water.

In 1990, a local civil society called *Samaj Parivartan Kendra* (Centre for Social Transformation), in collaboration with the Water Resources Department (WRD) of the state, motivated farmers to take over the operation and management of the scheme. At the outset, only three Water User Associations were formed at the tail area of the canal command. Initially, these WUAs struggled to get their share of irrigation water. But with the transfer of management to WUAs, farmers in the tail area received their fair irrigation water quota and thus could irrigate the more cropped area.

Enthused with the success of the WUAs, farmers from the entire command gradually formed twenty-four WUAs. As a step forward, in 2003, all the WUAs came together and managed the operations and maintenance of the whole irrigation scheme by creating an apex organization called *Waghad* Project Level Water Users Association (PLWUA).

Functioning of PLWUA: The PLWUA undertook water management with technical guidance and support from WRD. Water was supplied volumetrically at the head of the canal, and subsequently, the PLWUA distributed the water among other WUAs as per their demand and entitlements. As the average landholding of farmers was minimal (0.5-1.0 ha), volumetric supply to each farm holding was complex, so farmers devised an innovative way to share water on a timely basis.

The association collected water charges from its members and used them in the operations and management costs of the system. Management transfer to PLWUA resulted in 100 % utilization of irrigation potential, water-saving, crop diversification, and 100 % collection of water charges.

Innovative Water Management by PLWUA in *Waghad* Project resulted in 13 MCM of saved water in the irrigation year 2008-2009, almost one-third of the water diverted for irrigation. During the period 2003 to 2008, the area irrigated increased from 7,377 ha to 10,400 ha, the water uses in ha/ MCM increased from 218 to 300. In addition, the farmers were able to grow high-value crops like grapes, vegetables, and flowers, along with traditional crops like rice, *bajra* (Pearl millet), sorghum, wheat, gram, etc. The farmers' income in 2003-2004 was INR 60,000/ha which doubled to INR 120,000/ha in 2008-09. This management technique generated local employment and reduced the migration of farm labourers from villages to cities.

Based on the success of participatory irrigation management in the *Waghad* project, the Government of *Maharashtra* (GOM), India, decided to facilitate the supply of irrigation water by forming WUAs only. This efficient water management model was projected to be replicated at different locations in the country and other developing nations of the world.

4.5.3 Water Conservation by Use of Sprinkler & Drip Technologies in Paddy Crop

Submitted By: Mr. Karan Jeet Singh Chatha (2019)

To improve water use efficiency and increase crop productivity in paddy fields, an integrated water management technique was adopted in *Haryana*, a northern state in India. The state is an important economic centre for growing export quality rice; however, the last decade was marked by depleting water tables and increased water scarcity. To work on these issues, a water conservation model was implemented, and sprinkler and drip technologies were used extensively. From a water management's perspective, the situation was looked at from two angles- Supply augmentation-increasing the available supply by the reduction in conveyance losses: and Demand management - increasing the field application efficiency with the use of water-efficient sprinkler and drip irrigation technology.

This technique was implemented as part of a pilot project prepared by the regional Command Area Development Authority to install community-based Minor Irrigation (MI) schemes in 13 different districts of the State of *Haryana,* covering an area of 2,231 ha.

Common Micro-irrigation infrastructure was provided for each canal outlet command for supplying pressurized water supply at the farm gate of each farmer of the outlet instead of constructing lined field channels. The department constructed a community-based water storage tank, pumping unit (Grid/solar powered), filtration unit, HDPE pipe network, hydrant/outlet assemblies, and valves. It aimed to promote the Water User Association and inculcate a sense of ownership amongst farmers for better water management and ensure that every farmer gets its due share of water in turn.

The Water Users Association (WUAs) provided land to construct a community pond for storing water from the outlet and supplying it further to individual farmers. Additionally, the management of the water was done entirely by the shareholders. With coordination between the farmers and the department for planning, execution, and monitoring, management was transferred to the WUA.

The project was implemented in 2017 at the identified paddy field growing variety PR 126 to demonstrate the benefits of micro-irrigation. For comparison, on a separate plot of 1-acre conventional flood irrigation method was used. Irrigation was done in the other 2 acres of the plot, with each acre following Sprinkler and Drip Irrigation methods. All three fields were under constant monitoring and observation.

After the crop was harvested, it was found that in the fields with micro-irrigation, the increase in yield was 290 kg/acre, and almost 42% of the water was saved. Considering the quantity of water saved and improved productivity of the experimental plots, the project was extended to another 9 acres in which 3 acres were sown by Direct Seeding Rice (DSR), 3 acres by mechanical trans-planter, and 3 acres by traditional manual methods. This comprehensive study resulted in more than 50% water-saving and increased yield from 45% to 59%.

The extended project was taken up in collaboration with Hissar Agricultural University. Irrigation was done by Sprinkler Irrigation, Drip Irrigation, and Flood Irrigation methods. It was concluded that Micro-irrigation techniques increased water-saving and the yield in the water-guzzling paddy crop. For further expansion, a Public-Private Partnership (PPP) scheme was formulated according to the Government's objective to enhance irrigation efficiency, productivity, and farmer's incomes. Another critical element behind the success of such initiatives is the organized operations by the farmers and other end-users in the farm sector. To ensure sustainable strategies and equitable water distribution to tail-end farmers, associations at the local should be promoted who can also maintain the systems.

4.5.4 Effective Water Management through Farmer's Cooperative Interventions

Submitted By: Dr. Vijay Sharad Deshmukh (2017)

Vidarbha region is in the eastern part of *Maharashtra* state of India. Western districts of *Vidarbha* in the *Warud* region are drought-prone areas. The average annual rainfall in the region is around 800-900 mm while water storage is minimal. Over the past several decades, erratic rainfall and shrinking river flows have substantially reduced the water table in the block, thus, posing a major threat to its primary sector - agriculture and thus the socio-economic status of inhabitants. Lack of irrigation facilities has left farmers utterly dependent on rain-fed farming, which is unstable. Once known for its rich agricultural produce, especially mandarin, the region struggles with grave water management issues.

Old irrigation structures like KT weirs suffered from limitations like poor grid connectivity, additional costs of diesel pumps, and erratic delivery mechanisms. As an integrated effort from the community and the government, a distribution chamber called *Chudmani* was built with a 200 mm pipeline to bring water from an 11 km distance in such a way that it provided a natural head for the drip irrigation system, thus eliminating the use of electricity/diesel pumps. Four water filtration units were installed, which used sand to filter the water. A water meter was provided at the off take to increase transparency in water use accounting. During the project, 0.5 MCM of water was reserved. One important aspect was that the added water was also diverted to wells during the high monsoon period to recharge the groundwater tables.

The project used the lift irrigation method to deliver water to the beneficiaries. Due to poor grid connectivity, the diesel pumps were an additional cost burden. In addition, water wastage was rampant in the peak monsoon rain season. The new system catered to these issues.

The project saved approximately 159,524 kWh of electricity based on a 6-months usage of drip irrigation. Considering the life of the project, the entire savings outweighed the investment costs, making it highly profitable, financially viable, and environment friendly. Moreover, there was no carbon footprint. The water table recharge during peak monsoon ensured the sustainability of water resources in the long run. Water usage efficiency was between 95%-100%, thus, minimizing the wastage.

Drip irrigation reduced dependence on labour and solved the problem of erosion. It was estimated that the average farmer's income rose by 35%-42% per annum. Out of 140 ha cultivated, 87 ha was under citrus fruits like oranges and citrus limetta. The project enabled farmers to add 53 ha to citrus fruits further. The assured water availability increased yield per ha. The overall results were beyond the set expectations of 0.6 MCM water and 59 beneficiaries in a parcel of 82 ha in *Warud*. After the project, the area under irrigation doubled to 145 ha and the number of beneficiaries reached 165. The existing capacity of the project is 212 ha which can be expanded up to 360 ha.

Figure 4.16 Distribution Chambers

This technique demonstrated a successful intervention by farmers cooperatives with active support from the government in the form of water dues paid on time. With committed actions from farmers cooperatives and support from the government, the region became water sufficient.

Such institutional models and irrigation systems can be replicated in other drought-prone areas of the region with capacity building. The farmers' cooperative society can share their best practices and train future beneficiaries.

4.5.5 Saguna Rice Technique – Zero Till Conservation Agriculture

Submitted By: Mr. Chandra Shekhar H. Bhadsavle, Mr. Changdev K. Nirguda and Mr. Anil D. Nivalkar (2016)

Saguna Rice Technique (SRT) is a new method of rice cultivation and related rotation crops without ploughing, puddling, and transplanting (rice) on permanently raised beds. This zero-till Conservation Agriculture (CA) method was evolved at *Saguna Baug, Neral, District Raigad,* in *Maharashtra,* India. About 1,200 farmers reported overwhelming results after using the technique.

SRT requires no-tilling and provides oxygen and organic carbon for the rhizosphere, the natural ecosystem around the roots, to flourish organically. The Rhizosphere benefits greatly from the permanent raised beds system. These raised bed systems facilitate the adjustment of moisture to optimum levels promoting vigorous, hairy white roots and vibrant, wider leaf lamina resulting in crop growing uniformly and delivering a higher yield.

Figure 4.17 Saguna Rice Technique demonstration

SRT facilitates the planting of crops at predetermined distances enabling precise plant population per unit area. The absence of puddling and transplanting of rice reduces the dependency on rain or erratic rain patterns that prevent cracks leading to the death of crops.

The technique reduces water requirement by 50% for rice cultivation, reduces labour by 50% (no puddling, transplanting, or hand hoeing required), and reduces the cost of production by 40%. It also stops the emission of greenhouse gases and effectively sequestrates carbon to improve soil fertility. Fundamentally, SRT promotes retaining the previous crop's roots in the raised bed. The capillaries formed by dead, dry roots and earthworm pathways facilitate quick draining of rainwater resulting in effective recharging of aquifers. Other benefits of SRT include loss of silt (about 20%) during puddling, thus maintaining the fertility of the land, avoiding puddling, drastically reducing diesel consumption, and the emission of CO_2 and methane. Rice plants on SRT beds seem to be broader and head upwards to sunlight more than their counterparts in the conventional method. They are likely to produce more biomass leading to higher or similar yields in all soil types.

Microorganisms and earthworms are important aspects of plant growth. Many earthworms were noticed on SRT beds during high rainfall, and they also attracted unusual birds to the plots. Suppressed and decayed green growth with Glaypho set becomes instant food for the worms, and 'No-Till' prevents dead worms. The root network prevents soil from cracking and makes it spongier. The same roots become a valuable source of organic carbon uniformly distributed, and oxygen pathways to the root zone of the next crop.

The shocks caused to the rice seedlings during transplanting are avoided in SRT. This reduces the possibility of pest and disease problems; crops can be harvested 8–10 days earlier, and it also saves time required for soil tilling between two crops which leaves valuable 10–15 days of crop season for the farmer to take more than one crop in the same plot in a year. SRT yields a higher percentage recovery of grains. No use of heavy agricultural machinery for tilling in the field prevents compaction and hardpan formation of lower strata of soil enabling better percolation of water into deeper soil and permanent establishment of earthworms.

SRT ensures a higher return to the tune of more than INR 500,000/ha with crop rotation such as Basmati Rice (PS-5) in *Kharif* (monsoon) season, leafy vegetables in *Rabi* (winter) season, bold Groundnut (W-66) in summers while improving the soil health at the same time.

This technique could be the best solution for natural calamities such as hailstorms, floods, cyclones, and untimely rainstorms, as the crop cycle is shortest and involves multiple choices of short-term rotation crops such as pulses vegetables, onion, sunflower, groundnuts, and so on. SRT can recover from damages caused by lashing, scrubbing, and degradation of soil by natural calamities in the quickest possible time. In this method, tilling the soil and making raised beds are required only once. The same beds can be used repeatedly to grow various rotation crops after rice in the monsoon season.

SRT Planting Method: First, the soil is tilled, and the raised beds are developed only once, the best time to make these beds is immediately after the monsoon paddy harvesting. Good ploughing and tilling are done with available residual moisture or through irrigation with organic manure with a rotavator or power tiller. Secondly, parallel lines are drawn with the help of rope and lime or wood ash at 136 cm apart; depressions are made with SRT iron forma on the raised beds, fungicides or beneficial microorganisms are applied to the seeds as per the guidelines. Thirdly, the plot is irrigated, followed by pesticide application (Oxyfluorfen 23.5% EC @ 1 ml/l of water after 3 to 4 hours). When the crop is ready for harvest, the plants are chopped, leaving the roots with 2-3 inch of stem in the beds. Roots from previous crops are kept in the soil while Glyphoset (15 lit water + 70 ml Glyphoset + 200 g of sea salt or 150 g of Urea) is sprayed for 2 to 3 days after harvesting.

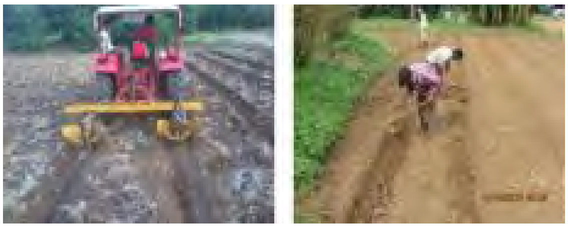

Figure 4.18 The plantation process

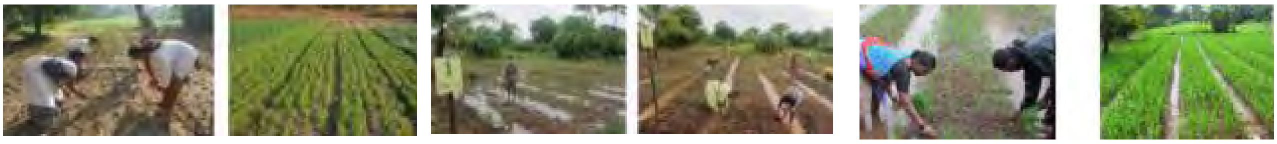

Figure 4.19 The harvesting cycle

SRT is a customized cultivation practice with multifarious benefits. It has improved yield, reduced water consumption, and has other environmental benefits. Above all, it reverses the trend of farmers giving up rice farming. The innovation should be replicated in other regions and crops.

4.5.6 Group Farming and Micro-irrigation – A Way to Prosperity

Submitted By: Bhagwan M. Kapse (2015)

To bring the farming community together to share costs and investments in the face of economic adversity and limited resources, a farmers' group was established in 2000 with farmers from five villages in *Jalna* district in *Maharashtra*, India. The group started agricultural production with a small mango orchard and implemented modern techniques such as drip, sprinklers, mulching, advanced agronomy, and crop protection management.

It resulted in higher farmer productivity and quality of production. These small farmers who were unable to bear the high investment individually benefited from the sharing mechanisms of group farming. Some of the objectives of the Concept of Group Farming are:

(a) Identifying and bringing together farmers with everyday needs, opportunities, and potential.

(b) Developing clusters among farmers with shared experience, orientation, and farming aspirations

(c) Adopting and implementing a suitable mutually decided cropping pattern on a large scale through these groups and federation of these groups in a cluster of villages

(d) Implementing modern technology in the field with shared costs and risks for a high-quality produce

(e) Adopting advanced irrigation systems like drip and sprinkler and increasing water use efficiency

(f) Developing community-based land and water conservation practices

(g) Community-level commitment to cover all crops including cereals under micro-irrigation, with stern regulations of no water availability to fields without Drip or Micro Irrigation

With the increasing group strength and the number of such groups, the average increase in the yield was 2 to 4 times, and 50% irrigation water was saved with the adoption of drip irrigation. Drip irrigation was especially beneficial in the production of cotton; the productivity improved from 3,000 kg/acre to about 7,500 kg/acre, which is 4 to 4.5 times more than the normal yield.

The increased yield in individual crops with the use of group farming is briefly presented in Table 4.1:

Table 4.1 Increase in Yield

Crop	Yield/Acre (Before) (Quintals) (1 quintal= 0.1 tonne)	Yield/Acre (After) (Quintals)	Increase
Cotton	6-10	25-30	3-4 times
Tur (Pulse)	6-7	15-17	2.5 times
Soybean	7-9	15-18	2-2.5 times
Wheat	10-15	25-30	2-2.5 times
Mosambi (Citrus)	4-5	15-18	3-3.5 times
Pomegranate	4-5	10-12	2-2.5 times

Drip irrigation was further expanded to almost 90% of the area under cultivation. The annual per capita income of the farmers increased from INR 41,842 in 2007-08 to INR 106,406 in 2012-13 in water scare *Khamkheda* village.

Small and marginal farmers were the biggest beneficiaries of group farming management techniques, leading to resource pooling and risk sharing and ultimately increased income. These practices can be further replicated in other villages, primarily through monthly programs like *Dwadashi* meetings. These meetings are organized to disseminate learning, discuss the technologies adopted, and share experiences with farmers, government officials, and the community.

Figure 4.20 The 110th Monthly *Dwadash* meeting group lunch

4.5.7 Efficient Utilisation of Rainwater and Exploring Options for Conjunctive Use of Water in Canal Command

Submitted By: Dr Ashutosh Upadhaya (2017)

In the past decade, *Bihar*, one of India's eastern states with rich natural resources, faced low agricultural productivity due to an underdeveloped groundwater infrastructure and other issues like increasing population pressure, poverty, small and fragmented landholdings. Even though good quality shallow groundwater aquifers were available, the infrastructure was only available for 42% of the reserves and could not be utilized in crop production. Farming activities were heavily dependent on the annual monsoon, which were often delayed leading to lower crop yield. In addition, the subsequent wheat production after rice was also affected.

So, a management technique for the conjunctive use of water and a decision support tool was developed on a visual platform that facilitated real-time scientific decision-making. It also improved the farmers' adaptability rates of efficient water use patterns. It led to the effective use of rain and surface water in agricultural production and the enhanced yield of rice and wheat crops.

Following two main innovations were developed and demonstrated for implementation.

(a) Dykes of 20-25 cm were created around rice fields instead of 7-15 cm to store up to 90% of the rainwater in the field and increase rainwater use efficiency. It reduced runoff and soil loss, increased groundwater recharge, and saved water in at least one or two irrigations that were earlier dependent on the canals.

(b) Farmers were encouraged to explore the utilization of untapped groundwater along with canal water and rainwater harvesting. Conjunctive water use demonstrations were conducted through the user-friendly decision support tool in English and Hindi (native language) using Visual Basic Platform.

In a rice nursery, farmers applied two to three irrigation cycles through groundwater, and 1/10 to 1/15 of the transplanted area was irrigated using rain and canal water, reducing the complete dependency on one source. This also increased crop production substantially. In addition, when farmers created dykes of 20-25 cm (in place of existing 7-15 cm) around rice fields, they efficiently utilized up to 90% rainwater. The canal water requirement for a one-two irrigation cycle was also reduced.

Figure 4.21 Demonstration of dykes around rice fields

Figure 4.22 Demonstration of Conjunctive use decision Support Tool

Initially, only a few farmers adopted this technique. Gradually, more farmers joined and adopted the dyke system in their fields. It not only led to rainwater utilization up to 90% but also renewed groundwater reserves and tables, reduced surface runoffs, and at the same time controlled the soil losses. Since implementing this innovative technique in Bihar, many good-quality shallow groundwater aquifers have been replenished.

4.5.8 Building Farm Level Capabilities to Adopt Climate Change

Submitted By: Kaluvai Yella Reddy, Udaya Sekhar Nagothu, Kakumanu Krishna Reddy and Llati Narayan Reddy (2017)

Among all the major cereal crops grown in India, rice constitutes about 24% of the total food grains, almost 103 MT of the total agricultural produce. Around 95% of the cultivated area under rice requires about 12,000–25,000 m^3/ha of water, depending on the soil texture, structure, and profile conditions. The conventional rice cultivation method adopted in the country is transplanting seedlings in ponded water. With growing climate uncertainty and erratic monsoon patterns, it has become unsustainable. Additionally, emissions from flooded fields pollute the environment. Moreover, delayed onset of monsoon, insufficient irrigation water at tail ends of canal commands, increased labour requirements, and the increasing costs called for a structural management shift.

The ClimaAdapt programme was thus developed and implemented in the *Guntur* district in Southern Eastern coastal state *Andhra Pradesh* of India. The framework focused on key areas - upscaling the technologies, situation analysis, capacity building, implementing adaptation measures, and strengthening the science-policy linkages between research, innovation, and capacity building.

The implemented action plan on the ground was as follows:

(a) Sustainable practices like Direct Seeded Rice (DSR) and Alternate Wetting and Drying (AWD) for rice cultivation were promoted. Identified key indicators were adaptation rate, average total income, the area under technology adaptation, the quantum of water saved, application of knowledge by the people, and compensation received for weather risk.

(b) Capacity-building and conservation activities were organized based on situation analysis and available technologies. Knowledge dissemination and awareness creation were conducted through booklets and videos used for training. Implementation was done following a cluster-based approach, keeping water users' associations as focal points.

(c) The measurement of water and quantified irrigation water release was prioritized to educate all the stakeholders. Farmers were trained to irrigate fields efficiently.

(d) The project also developed a prototype sensor assembly called 'TWEET' to measure water level, temperature, relative humidity, and soil moisture. Ultrasonic sensors were used to measure water depth, both in the flume and in the field. The sensors were installed in sixteen places in the project area on the canals and in the farm fields, where it was safe and convenient to install and access information.

(e) DSR was practised through dry seeding and wet seeding. In the case of dry seeding, seeds were sown directly into dry soil at a depth of 2-3 cm immediately after the pre-monsoon showers. The method was suitable for rain-fed and irrigated environments with precise water control.

(f) In irrigated areas, the dry seeded fields were also converted into wet methods based on water availability from canals. After sowing, irrigation was provided for 45-60 days and then managed as a wet system.

(g) Pre-germinated seeds were broadcast or sown in the puddle soils in wet seeding. The wet method saved labour costs as compared to dry seeding. It was found that drum seeded rice using the wet method was beneficial, where seeds were sown in line with the puddle soils.

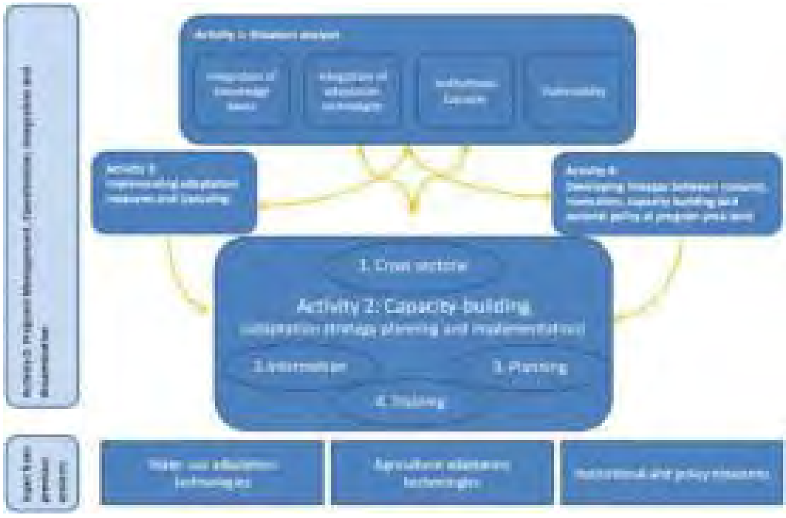

Figure 4.23 Programme Framework

DSR adaptation saved the cost of cultivation, water, labour, and time with reduced greenhouse emissions, mainly methane. The total methane emissions from traditional rice transplanted fields were estimated to be 315 kg CH4/ha. In contrast, for DSR, the estimated methane emissions were 220 kg CH4/ha during *Kharif* (monsoon) season.

With the adaptation of DSR, about 9,805 tons of CH4 emissions were eliminated. The cost of cultivation was reduced up to 10,000 INR/ha due to less labour and seed requirements. Labour requirement was dramatically reduced in comparison to the traditional rice cultivation method. About 25 to 37 labourers/ha were required for rice transplanting, 50 for weeding/ha, and about 25 person-days/per hectare for harvesting. Hence, the labour cost was significantly decreased.

The method was validated on farmers' fields from 2010 to 2015 to generate relevant biophysical observations and economic data. A study was conducted under the NSP area of the *Krishna* River basin. Total 14,051 farmers (including 22% of women) were trained on various aspects through field days, exposure visits, exhibitions, seminars, webinars, and workshops.

Village Knowledge Centres (VKC) were established in the project area to promote water and climate literacy and advisory services on crop planning, pest, and disease control.

The project successfully developed Policy Manuals "*Climate Change Adaptation in Agriculture and Water Sectors: Policy Inputs*" for both *Andhra Pradesh* and *Telangana* states of India. The area under the DSR system in 2010 was limited to only 100 ha and increased to 400 ha by 2011. In 2012-13, the area grew to 20,000 ha. There is still scope for further expansion in the *Krishna* Delta to the extent of 0.4 Mha.

The ClimaAdapt project made substantial progress at the field, institutional and policy levels by highlighting the impact of climate change and the need for saving irrigation water in paddy cultivation. The technique can also be considered for large-scale implementation by the other state governments in India. The Government of India (National Water Policy 2012) also encourages water-saving and increases water use efficiency. Following this approach, farmers all over the country can be incentivized for the procurement of seed drills, mechanical weeders, and the extensive use of water-saving irrigation techniques.

4.5.9 Predicting Hydro-Economic Potential of A Rainwater Harvesting System

Submitted By: Pramod Pandey (2013)

Rainfed farming systems in Eastern India are adversely affected by frequent droughts and poor rainwater management practices. Because of the dwindling water supplies and declining water tables, greater emphasis is given to conserving the in-situ rainfall in the diked crop field by harvesting it in the reservoir and then using it for supplemental irrigation of crops. The Eastern region of India has ample rainfall resources with an average annual rainfall of 1500 mm, 80% of which is concentrated during the monsoon season between June to September.

The reservoirs constructed in the farms are used for multiple purposes. It is estimated that there are more than 7,50,000 reservoirs of varying sizes in the region. Although they have been used since ancient times, they were only developed exclusively for crop–fish integration in the last decade or so. Effective rainwater conservation and management practices were also adapted to achieve sustainability and economic stability.

A reservoir was constructed to harvest the runoff water generated from the diked rice fields. The harvested runoff in the reservoir provided supplemental irrigation for rice during the monsoon season and pre-sowing irrigation for mustard in winter. Additionally, the stored water was used for fish cultivation. The entire process increased the production and the productivity of crop fish integration per unit quantity of the harvested rainwater. Simulation studies were also conducted for daily water balance models of both the crop field and the reservoir to ascertain the availability of water in the reservoir for fish growth and to meet the irrigation demand of the crops.

A model to simulate the hydro-economic potential of rainwater harvesting systems in rain-fed areas was developed. The model simulated crops' readily and non-readily available soil moisture, additional irrigation requirements, and water storage in rainwater harvesting reservoirs. It also calculated crop yields, surface and groundwater availability, and net value gains. The approach developed was capable of predicting potential hydro-economic benefits of an on-farm reservoir (OFR) system under various climate conditions, which helped promote water-saving in dryland areas.

A comparison between the net gross return of a distributed OFR system and a large, centralized reservoir indicated that the net gross return of the distributed OFR system exceeds the net gross return of the large reservoir, suggesting that the proliferation of distributed rainwater harvesting system can play a crucial role in improving water-saving in rainfed regions.

Results suggested that the rainwater harvesting in OFR has a potential for improving fish and crop productions in rain-fed regions considerably, improving the income and livelihood of millions of small farmers living in areas with water scarcity. Overall, the technique showed positive results. These techniques were proven suitable for both large and small farmers. Large farms had lined reservoirs while small landholdings installed unlined ones. The average farm sizes ranged from 3 ha with a reservoir size of 2,000 m^2 to 0-5 ha with a reservoir size of about 100 m^2.

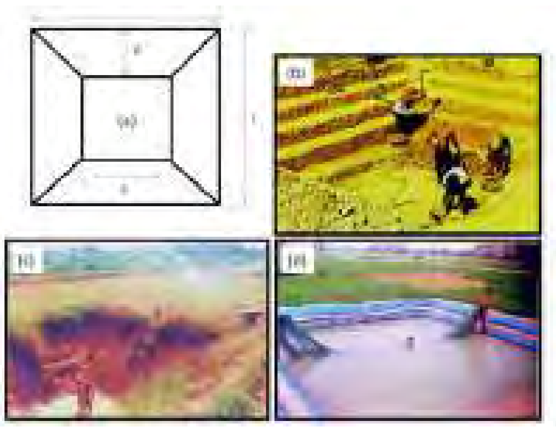

Figure 4.24 On-farm reservoir designing. (a) Design illustration; (b) field scale OFR designing; (c) supplemental irrigation to crop land; and (dD) fish harvesting from the OFR.

Groundwater availability also increased by 18% and provided supplemental irrigation, resulting in increased crop yield by 30 – 40%. The increase in total gains from improved crop yield and water availability were considerably higher in the OFR system when compared to the conventional rain-fed system. For instance, the total value gains for the OFR system were 31 – 74% greater than the rain-fed system. The study revealed that rainwater harvesting in the reservoir for crop–fish integration has a great potential in the rain-fed farming systems in Eastern India. The rainwater storage in the reservoir and its recycling processes conserve natural resources like soil and water of the cultivable land, which increases the yield potential of rain-fed crops.

4.5.10 Innovative Irrigation Management by Federation of Water User Associations in Waghad Irrigation Project, India

Submitted By: Shahaji Manikrao Somawanshi & Bharat Kawale (2008)

Waghad dam project on river *Kolwan* is a medium irrigation project commissioned in 1981 in *Nashik* district in *Maharashtra* state of India. Over the years the need for active community participation in its operation and management intensified. This realization led to the creation of the Water User Associations (WUA), which was revolutionary for the time.

After overcoming many challenges with the support of '*Samaj Parivartan Kendra*', a non-governmental organization, three WUAs (named *Banganga*, *Mahatma Phule,* and *Jai Yogeshwar*) were developed in the *Ozar (Mig)* area. It covered 1,151 ha in the year 1990. These WUAs functioned independently in their jurisdictions but later came together to form an apex organization at the project level. In total, 24 WUAs established the Federation of Waghad Project Water Users Association (FWPWUA) in 2003. The State Government formally handed over the entire management of the Dam to the Federation in 2005.

FWPWUA's main functions were equitable distribution of water amongst WUAs, operation and maintenance of canal system, collection of water charges, resolving dispute amongst WUAs, if any, and representing farmer's interest while coordinating with the government.

The Federation managed the Waghad Dam with support from the irrigation department. A yearly water utilization chart was prepared and monitored by the WUAs. Water was supplied volumetrically at the head of the canal and then among associations as per their entitlements. As the average landholding of farmers in 2003 was 0.5-1.0 ha, volumetric supply at an individual level became difficult, so command area distribution was practised. The Federation also managed water charges from its member associations and won the government's confidence with its efficient financial model. Conjunctive water sources and extensive use of drip irrigation systems were also promoted in the area.

With FWPWUA's management, water use efficiency was achieved by optimum utilization of water as well as guaranteed water entitlements. Roughly 2,523 wells were recharged, increasing water availability and expanding the irrigation area. The production of high-value crops like Grapes, Vegetables, Flowers, and Sugarcane, increased in the region.

Employment was generated as well, as the income for the farmers enhanced over the years. The productivity increased drastically from 1990 to 2006-07 from 2,500 INR/ha to 1,05,000 INR/ha. The water use efficiency improved from 218.18 ha/m^3 in 2003 to 297 ha/m^3 in 2008.

Management transfer to FWPWUA resulted in water conservation, regulated and timely crop rotations, control on malpractices, the development of management, and social leadership within the community. This innovative endeavour saved roughly 13.27 MCM of water in 2007-2008, almost 1/3rd of the water supply for irrigation.

The system's water-saving and efficiency kept increasing in the following years leading towards sustainable irrigation management. The federation's success influenced the state government to promote the formation of water users' associations in other regions as well. FWPWUA's functioning is an example of the community's involvement in the operation, maintenance, and effective decision-making concerning the project.

4.5.11 Group Farming Using Drip Irrigation

Submitted By: Laxman Sakharam Sawade (2012)

Large-scale production, grading of agricultural produce, packaging, efficient transport, and cold storage, among other factors, are necessary for marketing crops by the farming community. However, poor farmers with small landholdings cannot afford these facilities. Even the expenses on fertilizers, seeds, and pesticides become cumbersome. Therefore, a group of farmers formed a farming group called Agro India Horticulture in 2005 and cultivated a single crop on a large scale in *Jalna* district, *Maharashtra*, India.

Considering the area's geographical, soil, and meteorological conditions, horticulture was promoted. Group farming and group management of crops using drip irrigation and other micro-irrigation systems such as inline drip and sprinklers and mulching enhanced the agriculture income and led to sustainable development. Crops like cotton, pomegranate, soybean, wheat, tur, maize, and gram were cultivated under the project on 4,800 acres (1,942 ha) area.

Almost 920 farmers came together to form the group. Earlier, under gravity flow irrigation, 4,800 acres (1,942 ha) of farmland required about 5.6 MCM of water annually. But by using the drip and group farming technique, the annual water requirement came down to about 2.8 MCM. Hence, about 2.8 MCM of water was saved every year due to this approach and the micro-irrigation techniques.

4.5.12 Jalambadi- Krishna Model

Submitted By: Anga Tha (2012)

To raise awareness about water conservation and increasing water scarcity, a state-level campaign was organized on Water Conservation and Management (WCM) with a budget of 30,000 INR in *Krishna* district in the southern-eastern Indian state of Andhra Pradesh. It was called *Jalambadi,* meaning a 'school of water knowledge.' More than 200,000 students from 460 state high schools participated in the campaign and took an oath to conserve water.

Jalambadi campaign was implemented through different activities for the youth, school students, and the community. Directly or indirectly, over 300,000 families were sensitized towards the cause. About 500 headmasters from different schools acted as the programme ambassadors to disseminate the objectives of *Jalambadi* to the students.

The students were educated on how to conserve water and control wastage individually, domestically, socially, agriculturally, and institutionally through a concept paper on WCM and conservation principles. They were taught that even if one student saves water 1 l/ day, it can lead to about 9 MCM of conserved water in a year. The concept paper and the oath were disseminated and taught to students and teachers.

Some of the other activities conducted under the campaign were:

(a) Public rallies on water conservation were conducted with support from senior government officials and municipal authorities.

(b) Competitions like essay, drawing, quiz, debates, mock assemblies, and slogan writing were held at the school level in rural and urban areas.

(c) Exhibitions were organized to promote water-saving equipment like a rain gauge, infiltration rings, piezometer, anemometer, automatic water level recorder, resistivity meter, and casing pipe.

(d) Recognition and certificates were provided to the participants to appreciate their efforts and encourage others.

This experience created enthusiasm in the community. Given its tremendous effect on the community, the Water and Land Management Training and Research Institute (WALAMTARI), Government of Andhra Pradesh, declared *Jalambadi* an annual event in the state in collaboration with Ground Water Department. For further expansion of the programme, a logo was also designed with the slogan *Jalambadi pilupu - Jalasiri Podupu* (Call of Jalambadi - Conserve Water Wealth). Voluntary delegates also participated in the campaign in an All-India level Seminar on '*Conserve Water - Preserve Climate*' held at Hyderabad, Andhra Pradesh (now Telengana) in December 2011.

The World Bank appreciated the *Jalambadi* campaign, and the media described it as "The best awareness campaign".

4.6 IRAN

4.6.1 Applications of Constant Flow Rate Control Valve in Water-saving

Submitted By: Mr. Ali Mahdavi Mazdeh; Mr. Mohammad Bijankhan; Mrs. Narges Mehri; Mr. Hadi Ramezani Etedali and Mrs. Fatemeh Tayebi (2019)

In Southern parts of Iran, projects were developed to modernize an area of 55,000 ha using low-pressurized irrigation networks. An offtake called "Do Qolu" was proposed to distribute the water among the farmers. However, this offtake was sensitive to pressure fluctuations and was affected by conflicts between the stakeholders. A modular device working under low-pressurized networks proved useful in such a situation. This technique was also useful for vegetable-growing farmers around Qazvin who used tankers with heights between 5-10 m for irrigating using tapes in smaller fields. It helped them to increase the flow uniformity in the farms.

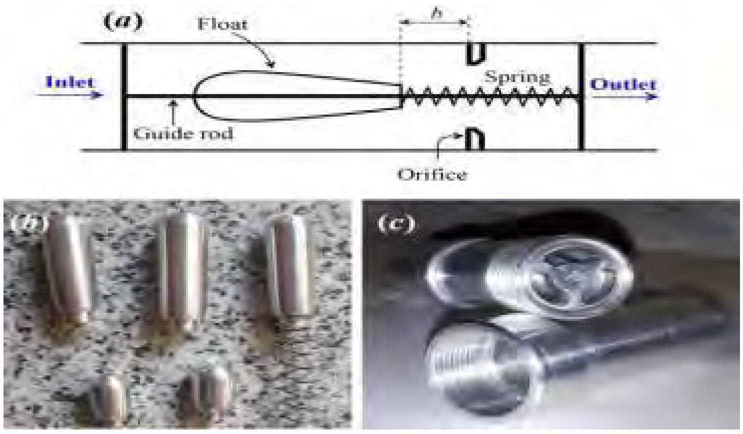

Figure 4.25 (a) MCOP schematic view, (b) Constructed floats, (c) A view of the constructed valve

The developed modular device was called Mechanical Choked Orifice Plate (MCOP), a discharge control valve. MCOP includes a float-spring blockage system inserted into an ordinary orifice that maintains a quasi-constant flow by being insensitive to both upstream and downstream pressure fluctuations. Some of its features are as below:

(a) The innovative MCOP valve was used i) for regulating a single pump with constant rotational speed, ii) in tape irrigation systems, and iii) for fairly distributing water in low head pressurized networks.

(b) The valve proved to be a useful device to regulate the pump operating point at its highest efficiency even if the total head-loss changed. This resulted in saving energy and preventing water losses.

(c) In pressurized irrigation systems, a pump is selected to provide the required pressure for the irrigation system in critical situations for an irrigation subunit with the highest head loss and elevation values. Therefore, pump efficiency remains unaffected when it is used to irrigate other irrigation subunits whose friction factors, local head-loss values, and ground elevations are different.

(d) Two important advantages of installing MCOP include: (i) Keeping the pump efficiency at the design value, and (ii) Maintaining the flow distribution uniformity for the irrigation subunits with different head-loss characteristics.

(e) MCOP can save up to 20% of the required water. It can also adjust the operating point of the pumping system without requiring electricity.

(f) For using MCOP as a constant speed pump regulating device, it should be installed at the entrance of the irrigation area. A constant design discharge should be considered with different irrigation areas, and the required demand should be provided by adjusting the irrigation duration. The pump should provide enough pressure to irrigate the critical zone.

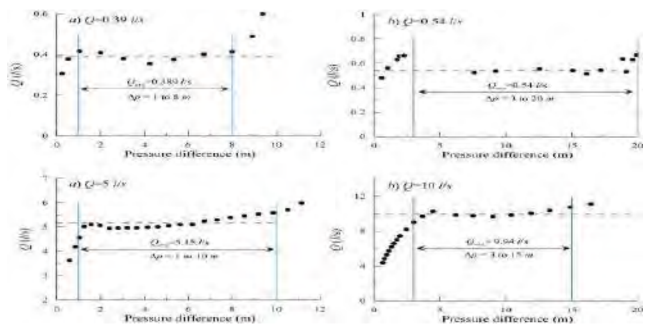

Figure 4.26 MCOPs' hydraulic behaviour; discharge versus differential pressure

(g) MCOP application in tape irrigation system: Irrigation tapes are sensitive to pressure fluctuation where no pressure-compensating emitter is used. For such a case, steep slope areas, non-levelled areas, areas close to the pump are sources of producing pressure fluctuations. In such cases, installing MCOP is an innovative solution.

A field study was conducted. An MCOP device of the design discharge of 0.39 l/s was fabricated and installed at the entrance of 247 m of tape lines. Pressures of 10 to 21 m were applied, with and without installing MCOP. For no MCOP installation case, any entrance pressure of greater than 10 m resulted in over irrigated condition and runoff.

Figure 4.27 MCOP with Q=0.39 l/s connected to two tape lines

It was observed that even up to a lateral pressure of 20 m or 30 m, MOCP was found to be able to regulate the flow. The observed average flow was found to be low. Whereas, in the case of no MCOP installation, the discharge per unit length of the tapes increased up to 19.88 and 21.28 l/hr/m for the lateral pressure values of 20 and 30 m against the discharge value of 14.25 and 14.86 l/hr/m, respectively. This established that water-saving of 19.4 % on an average and a maximum of 40.3 % was at the highest lateral pressure at design discharge -Q = 0.39 l/s and the corresponding water-saving values for design discharge- Q= 0.54 l/s were 31.3 % and 50.2%, respectively.

Figure 4.28 (a) No MCOP case with over irrigated areas (b) No MCOP case, tape explosion

The potential of the proposed flow control valve for expansion is significant. Pump regulation using MCOP is much cheaper than installing Motor Drives to adjust the pump rotational speed. The study indicated that MCOP can be used to adjust the pumping system's operating point, resulting in the best working efficiency and the least water losses. However, further research needs to be undertaken. A field study to quantify the water use efficiency is required. Designing a self-cleaning version of the valve for the muddy water and places with high sedimentation is a credible topic for future research.

4.6.2 Subsurface Irrigation and Tree Shades

Submitted By: Mr. Mahdi Afsari (2020)

The Faizabad-MahVelat area in Khorasan Razavi province is one of Iran's most essential pomegranates producing regions; however, it has faced extreme weather, rising temperatures, and water scarcity in the last few years. To promote pomegranate production, a favourable environment was created by implementing several techniques.

The problem of water scarcity was solved with drip and subsurface irrigation technology. But high temperatures and direct sunlight on trees caused problems such as the trees not absorbing the water they need, the destruction of the natural moisture, the withering of the leaves, insufficient breathing, and an increase in water consumption.

Awnings were designed for pomegranate trees and steam generators in the field. Columns were installed in the row of trees supported with 60% density lace nets placed over them. This reduced the intense sunlight on the tree and balanced the temperature preventing the loss of moisture. The design of the columns and the selection of nets used were in line with regional conditions (the presence of severe seasonal winds) and experiments performed earlier to have the least imposed costs.

The dimensions of a block of pomegranate tree orchards were 160 m by 100 m. There were 24 rows of trees along 100 m and 40 rows of trees along 160 m. Awnings were implemented in the row of trees along the 100 m, and the share of each tree in width was 4 m. In each row of 100 m, five columns with 25 m were installed.

The steps of the operation were as follows:

(a) Foundation of the columns in 5 rows of 100 m.
(b) Cutting profiles and scaffolding tubes according to the desired details by a skilled welder.
(c) Scaffolding columns buried in the foundation after concreting and installing profiles i on the plate after the concrete has been set.
(d) Plastic nets as well as longitudinal strips of tarpaulin with the desired dimensions placed on both sides by tarpaulin strips along the length.
(e) Nets to be spaced every 30 cm and then connected with rivets.
(f) Cables are cut as per the required size and connected by clamps in the required places.
(g) To prevent buckling of the columns, the beginning and end columns to be restrained to the foundation.
(h) Cables laid on the columns along the entire row, stretched and restrained at the beginning and end of the foundation.
(i) Using scaffolding and footboard, the nets with a width of 3 m, to be installed with great precision and step by step on low-end cables.
(j) Two cables are added to the grid installed along the length to prevent the nets from tearing due to strong winds.
(k) With wire, each of the rings is to be mounted on the grid connected to the side cables.
(l) Finally, after installing the columns of the side rows, the columns are to be welded to each other through a scaffolding pipe so that the assembly is connected. Then, the stretched set of adjacent rows connect by a cable at every 7 m.

Water consumption was reduced to almost 50% using this management technique. Before running the project, each pomegranate tree needed about 300 L of water every 5 days, but after the project, the water requirement reached approximately 150 L in 8 days. It also led to increased irrigation periods. The project began with a 100 ha of pomegranate and pistachio orchard, and the awareness campaigns and experience-sharing activities were organized for the benefit of other gardeners in the area.

4.6.3 Use of Waste of Pruned Trees as A Natural Mulch on the Garden Area to Facilitate Soil Moisture Maintenance

4.6.4 Combine "Neyrpic Module" Irrigation Method with the Traditional Iranian Irrigation Method

Submitted By: Ghazanfarpour – Mortaza (2019)

Rudashtain region is located at the far end of *Zayandeh Rud* basin in Iran. In the 1990s, traditional creeks were used to irrigate this vast area. Owing to this, the loss of water from the river to the fields reached more than 70%. And by the time the irrigation network was ready in 2002, the supply outstripped demand creating drought-like conditions and distress in the community.

The use of traditional creeks had five major problems:

(a) There was a considerable volume of water in wide creeks and the efficiency of the water transmission was very low (less than 30 %).
(b) It was not possible to supply water by gravity to the fields, and the poor farmers, who were mostly owners of small lands, pumped water from creeks to their farms which increased the production costs and the price of the water (water rate).
(c) Despite the release of water in considerable volume, only a small area of each period could be cultivated.
(d) Due to the irregularity in the flow of water and associated issues, the farmers refused to use the developed irrigation network.
(e) The complete shutdown or the water flood at the end of the irrigation network, especially at the tail end, was one of the major problems in the basin.

For fluctuations in the water source, a combination of "Neyrpic Modules" method, the dynamic regulators ("AMILLs" and "AVIOs") and static regulators (simple weirs, "Duck Bills" and "Labyrinths") were used to maintain a fixed supply quantity. "Neyrpic Modules" method replaced the conventional splitting methods. The concept of the combined system was based on the following design considerations:

(a) Sub-critical flow in "Neyrpic Modules" method resulted in a more uniform water profile velocity and the accuracy of the structure.

(b) To conform to the existing system, the "Diagonal Weir" was considered for the "Lat" structure

(c) To minimize the effects of the existing Duck Bill weirs (for "Up Stream" flow), the height of diagonal weirs was slightly higher.

(d) To eliminate the impact of the existing Duck Bill's, the gate in front of the weirs was opened completely.

(e) Given the existing Modules's high capacity all modules' gates were fully opened to increase the accuracy of the system.

The new concept comprised of "lat" or "Maqsam" meaning dividing and divisor, a traditional Iranian structure that is used to split the water as a share (percentage) between the beneficiaries. The use of this structure was quite consistent with the flow in the river. This structure was based on increasing the water level and dividing it based on the equivalent lengths of each village on the whole length of the weir or orifice hole diameter.

With the operation of the irrigation networks and the required structures, with the same volume and discharge (1.5 - 2 m^3/s at 80 days), the cultivated area increased almost 2.5 times (from about 1,500 ha to more than 3,700 ha). The conventional water requirement was (3 - 4 m^3/s at 80 days) for the same area. A significant amount of water was saved as the need to supply compensatory water resources (owing to water cuts and fluctuations management) was eliminated.

The delivery problem to tail-end farmers was addressed by adopting appropriate design and techniques. Following the implementation of the project, several appeals were filed by other farmers regarding its extension to the other networks.

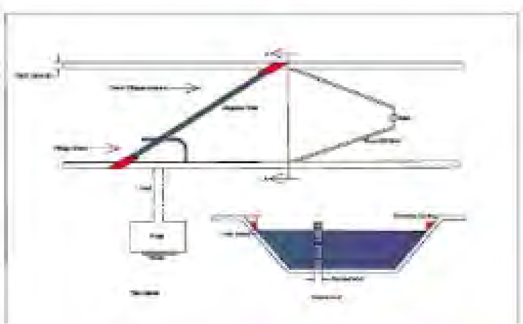

Figure 4.29 Plan and section of Lat structure

Figure 4.30 Performance of the built structure after the operation with discharge

4.6.5 Canal Fertigation, An Agro-Technique

Submitted by: Mr. Seyed Ahmad Bolandnazar and Mrs. Sousan Bolandnazar (2019)

Shortage of water in the past three decades in Iran and other arid and semi-arid regions throughout the world led to the increased dependency of agricultural production on scarce water resources. To manage water scarcity, a novel agro technique called canal fertilization was developed in an olive orchard farm after several years of experiments. The original inception was demonstrated through vegetable cultivation at the Japan Agricultural Research Center in 1985. It was later used in the establishment of olive, pistachio, and grape orchards in Iran.

In this technique, the olive trees were planted in the canals filled with a mix of plant residuals, organic matter, and microorganisms. These compounds make cellulose isolated media between the foliage ends of the channel and compressed weeds. It led to increased yield, minimal water usage, and enhanced nutrient use efficiency. The technique was implemented in an olive farm on Qm-Kashan Road, Fadak farm, Iran as follows:

(a) Two separate orchards were prepared for olive cultivation, one equipped with canal fertilization and the other following the traditional fertilization method of hole and control.

(b) Canals were prepared by digging channels with the desired dimensions (depends on tree type and crop) by a mechanical excavator. The appropriate width and depth for olive trees were 120 and 100 cm. Then, at 30 cm depth, the canal bottom was filled with the pruning tree branches.

(c) Eventually, 70 cm of the channel's depth was filled with weeds and cellulose. According to the amount of organic matter of soil, 50 - 90 ton of manure was distributed between two channels on the surface of the soil, mixed by ploughing.

(d) Finally, the soil surface of the channel was relatively flat and gravity irrigation occurred. Seedlings were cultivated 3-4 months after the channel preparation.

(e) This simple and inexpensive operation had many advantages, including an increase in trees survival, resistance to biotic and abiotic stresses, water drainage followed by prevention of root choking, and air drainage. The pores and aeration caused by branches in canal depth led to the exit of harmful gases such as ammonia from the root zone.

(f) In the hole canal method, holes with a diameter of 50 cm and depth of 70 cm were drilled. The holes were filled to a depth of 30 cm with foliage and straw. After that, the holes were filled with a mixture of one-third of the manure and two-third of the farm soil. After a few weeks, the hole was ready to cultivate.

In the traditional method, holes with a depth and diameter of 50 cm were drilled and were filled with a mixture of soil pits and a ratio of one second of the manure. The drop irrigation system was applied in all three methods. To measure the amount of water output per irrigation interval the plates were designed to be placed under droppers during certain periods. After a month, moisture of the root environment was measured by a digital moisture meter in all three samples. Findings revealed that the moisture of the root environment in the canal fertilization sample was 35% higher than the traditional fertilization of hole and control. It was observed that the 75% reduction of water consumption in the channel fertilizer method, has increased yield more than three times compared to the traditional method. In the hole fertilizer method, the 20% reduction of water consumption caused only an 11.6% increase in yield. Moreover, no symptoms of nutrient deficiency were observed in the leaves of olive trees on the farm. Given its success, the technique was also used in the pistachio orchard of *Astane Moghadas* in *Qom*, *Shahmaran* on *Kerman*, and a new apple orchard in *Damavand* area, Iran.

4.6.6 Reducing Water Consumption through Volumetric Charging of Agricultural Water

Submitted By: Naser Behmaneshfar (2018)

Dez Irrigation and Drainage Network (DIDN) located in the north of Khuzestan Province, Southwest Iran is famous for its fertile plain that allows two or three crop cycles annually. The network has been under operation since 1977, covering more than 90,000 ha of farmland. Since 1996, a 3% water cess was levied on a volumetric basis to promote water-saving among the farmers. With this strategy, the suppliers aimed to utilize water optimally while spreading awareness among the farmers about the actual value of water.

In June 2015, to further ingrain the value of water amongst the community, water bills were prepared on both volumetric use of water and the cropped area and the lesser of the two was the final payable amount. Out of all the farmers under 1,070 outlets with an average of 85 ha under each outlet and an average land holding of 5 ha, farmers of 40 outlets were invited for the first implementation phase. Commitments were made to provide the promised water supply as per their written requirements.

In the first year of the implementation, the consumed water of the area under the select 40 inlets was reduced by more than 5 MCM, by almost 5%. So, farmers paid 5% less worth of water bills. The second implementation year (2017) witnessed 234 inlet representatives who joined the program voluntarily. Farmers were motivated to reduce their water consumption and save money. This was achieved by imparting training on simple irrigation methods both in terms of their timings and quantity of water. A web-based software was also developed to improve network operation indicators such as efficiency, adequacy, equity, and network stability, which directly increased farmers' satisfaction. A tablet was given to each operator to immediately record the changes of the delivered water volume to the inlets which then allowed informed decisions.

According to a survey conducted in 2017 on the 234 inlets participating in the program, the average water consumption was reduced by 13.5%, saving 85 MCM of water on one hand while reducing farmers' water bills worth USD 72,000 on the other hand. More than 30% of the area under inlets in the Dez Network participated in the volumetric water contracts and other farmers also showed interest to participate in the scheme. This management technique holistically increases water efficiency, productivity and enhances the total health of the river.

Figure 4.31 The operator adjusts the flow of water and simultaneously recorded in the system

Figure 4.32 Training sessions of representatives of farmers

4.6.7 Controlling of Groundwater Level downfall Using Participative Management

Submitted By: Mohammad Mehdi Javadianzadeh and Mohammad Hossein Bagheri (2017)

Withdrawal of groundwater and rampant aquifer depletion in most of Iran's plains has led to negative aquifer balance and a rise in phenomena such as intrusion, subsidence, and sinkholes in the last few years. A participatory management technique attempted to control the groundwater decline in the *Abarkouh* County watershed containing two plains (*Abarkouh and Chahgir*) which are located in the west part of *Yazd* Province and have an average elevation of 1,776 m above sea level.

The mean annual precipitation and the annual evaporation of the area were about 65 mm and 3,200 mm, respectively. The cultivation area in this region was 12,000 ha and about 140 MCM of groundwater was annually extracted leading to the average decline rate of 62 cm/year. The main factor behind this depletion was excessive pumping for agricultural needs. There were about 700 wells in *Abarkouh* and *Chahgir* aquifers with a depth of 30-300 m (depending on geographical location and water tables). The storage coefficient of the *Abarkouh* and *Chahgir* aquifers were respectively 0.6 and 0.4. Since 1980 more than 1.1 BCM cumulative deficit of groundwater was recorded leading to a drastic drawdown.

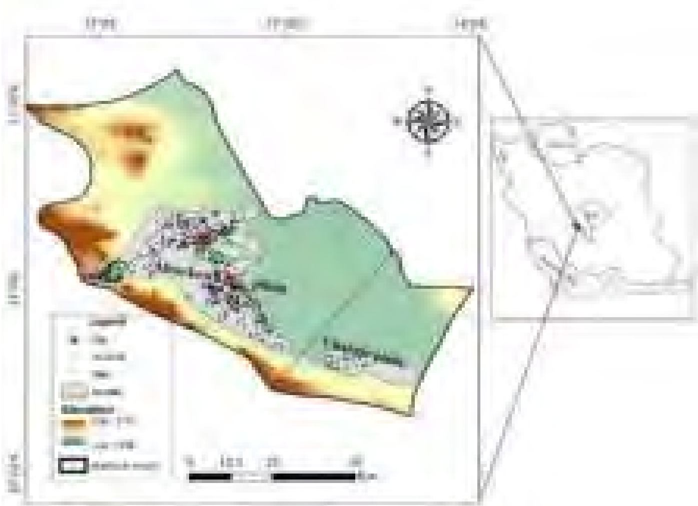

Figure 4.33 Project area: Abarkouh County Watershed

In response to the crisis, a participatory management technique was developed that propagated an integrated approach to save water in the agricultural sector and reduce overall consumption. From previous work, it was understood that the only way to control groundwater depletion was by reducing agricultural water consumption. Therefore, an *Abarkouh* Plains Coordinating Council (APCC), consisting of the governor, prosecutor, police, water resources, agricultural, environmental, and natural resources offices as well as several farmers and a university specialist, was formed. Monthly meetings were held for planning and coordination.

Firstly, all agricultural wells were equipped with smart counters to control withdrawals in 2014 and more than 90% of agricultural wells were equipped with this smart system by the end of 2015. - In 2016, farmers worked on water-saving practices. The allowed water right of each well was delivered to farmers by charging smart cards, simultaneously operations briefings and training were provided in the villages.

In *Abarkouh* plain, with more than 650 wells and 15,000 farmers, the smart countercharges were not collected in 2016 due to farmers' requests. All other agricultural wells also discontinued smart counters for one month per year. This further strengthened the long-term relations between the community and the authorities.

Before the above-mentioned plans, the minimum operation in each well was 8,000 hr/year, with an overdraft of more than 60 MCM. In *Chahgir* plain, withdrawal wells time was saved by up to 2,500 hours for each well in 2016. In *Abarkouh* plain, the water demand of total crops drastically reduced and all 650 agricultural wells with smart counters were turned off for one month, equivalent to 720 hours, from December 20, 2016, to January 20, 2017. More than 60% of agricultural wells in the project area were restricted to 3,000 hours from 8,670 hours in a year (24*365), and the rest of the wells up to 5500 hr/yr.

In the fifty observation wells in *Abarkouh* and *Chahgir* aquifer with only 1 mm rainfall in January 2017 and 17 mm in February 2017, there was a drought-like situation regarding the standardized precipitation index (SPI). However, there was a significant improvement in the groundwater levels as much as +27 cm in the *Abarkouh* aquifer translating to 15 MCM of water and +10 cm in the *Chahgir* aquifer translating to 0.66 MCM of water. Additionally, the groundwater quality remained intact as it was protected from saltwater intrusion. The figures below showcase these developments in detail. Ultimately, the groundwater volume increased over the years despite a consequent decline in rainfall; up to +15 MCM of water was saved indicating the positive results of the management technique.

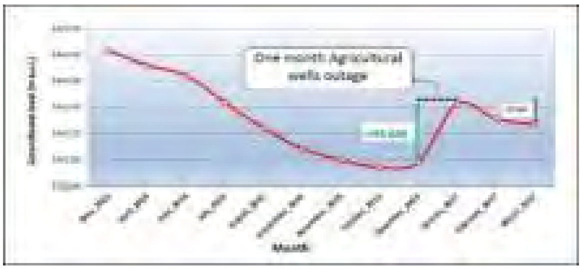

Figure 4.34 GW level variations in Abarkouh aquifer

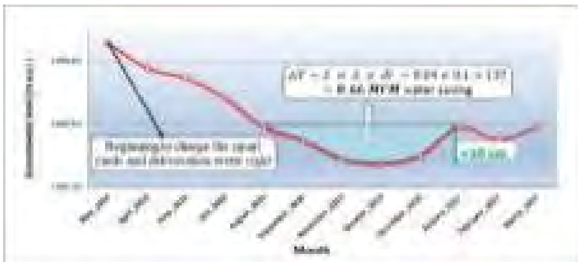

Figure 4.35 GW level variations in Chahgir aquifer

Figure 4.36 Electro Conductivity variations in Chahgir aquifer

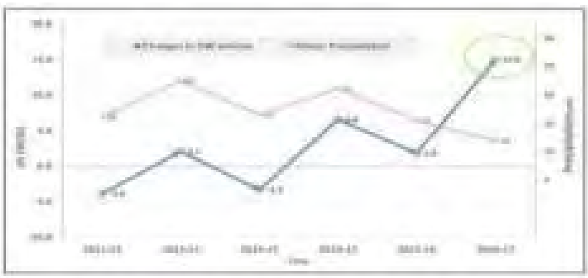

Figure 4.37 Annually changes in GW volume in Abarkouh aquifer

The management plan started in 2013 in *Abarkouh* and *Chahgir* plains was further extended until 2020. The operation was carried out based on the permitted hours and appropriate withdrawals. With increased time plans and cooperation from farmers, the impact area also increased. The execution plan is indicated below in Figure 4.39.

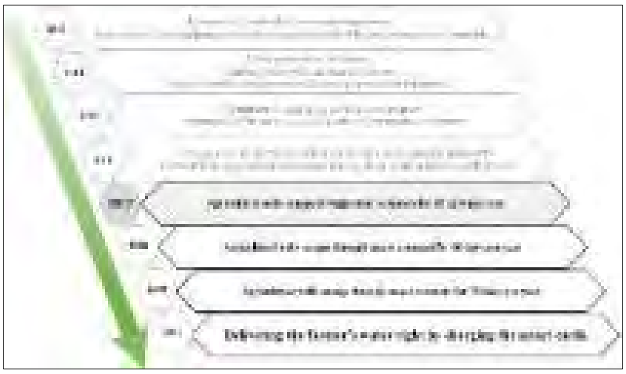

Figure 4.38 Yearly Plans since 2013-2020

4.6.8 Adoption of Good Agriculture Practices for Saving Water, Improving the Productivity, Income and Livelihood

Submitted By: S. A. Abd El-Hafez (2017)

Water scarcity and drought conditions are pushing the rural smallholders and farmers to apply and adopt the Good Agriculture Practices (GAP) in their fields to improve water productivity, increase water savings, boost their incomes, and rejuvenate the local economy.

The project included the development of a GAP-based field methodology and testing on demonstration sites with farmers. The community's response was also collected in the form of a questionnaire. These questionnaires included some information about the irrigation practices (time and number of irrigations, discharge of water pump in the irrigation improvement programs areas, width and length of the irrigated field, and the productivity of the demonstration and control plots before and after carrying out GAP and irrigation improvement processes (pipeline or raised lined irrigation canal, discharge of water pumps).

Field methodology included the selection of the farmers, data collection, soil and water sampling, and water table observation wells. Demonstration fields included the land of willing and literate farmers who can understand the purpose of the activity. The field demonstration aimed to help the farmers and WUAs follow and apply the latest GAP recommendation package of the Ministry of Agriculture and Land Reclamation and the Ministry of Water Resources and Irrigation. The demonstration fields were short-term fields, long-term fields, and irrigation canals. It showed suitable practices to increase soil productivity, improve irrigation efficiencies and reduce water losses. Questionnaires were used to evaluate the on-farm water management activities and to survey the adoption of GAP, including precision land levelling, relative long furrows, dry planting of clover, drill and row planting of wheat, and regular transplanting of rice.

GAP in the demonstration fields increased yield net revenue, saved irrigation water and enhanced the water use efficiency. Training programs were introduced for the farmers' technical personnel associated with the farming and water users' associations to build their capacities and improve their skills.

Precision land levelling increased the yield of different crops on an average by about 11.5 % and reduced water consumption by about 17.5 %. Furrow irrigation in the case of cotton increased the yield by 10.6% and reduced water requirements by about 15%. Land levelling along with dry planting of berseem clover saved water by about 13%, wet planting of cotton increased the yield by about 5% and saved up to 3% of irrigated water. Irrigation time for the summer crops in the demonstration fields was shorter than that in the control fields by about 23%. About 99% of the farmers in the demonstration fields and 97.1% of the farmers in the control fields realized the importance of precession land levelling, and about 44% adopted it. About 96% of the farmers in the demonstration fields and 37% of the farmers in the control fields realized the importance of relative long furrows, and 32% adopted it. About 77% of the farmers in the demonstration fields and 60% in the control fields had a positive outlook towards water management practices as a whole.

From a user's perspective, the adoption of GAP was successful in increasing production and reducing water consumption. This is a critical case study that can be replicated in other regions.

4.6.9 Decreasing Water Consumption in Agriculture by Operation Management and Providing Incentives

Submitted By: Hossein Emami (2017)

South Khorasan province is a dry and desert area of 151,196 km^2 in eastern Iran, with an average annual precipitation and evaporation rate of 100 mm and 92%, respectively. More than 30% of the region's employment and 29% of value-added services are in the agricultural sector despite ongoing water resource constraints. The total acreage of arable lands and gardens in the province is 1,89,739 ha, of which 32,036 ha in dry farms and 1,57,702 ha irrigated lands leading to excessive groundwater withdrawals. This, along with unstable rainfall over the past years and successive droughts, caused a 15% groundwater withdrawal overdraft. The drop in water levels and depleting aquifers created concerns of reduced cultivation area, reduced income, and increased production costs in industries, shortage of drinking water and social unrest, poor groundwater quality leading to additional purification costs, and rampant soil salinity and degradation of agricultural land.

Additionally, earth subsidence (silent earthquake) created cracks in the land, threatening sustainability. Plant species also degraded with the reduction in congeries and water availability. Studies showed that indiscriminate exploitation of wells, especially the licensed ones, was due to the lack of awareness among farmers and the inappropriate measuring tools and facilities available at their disposal.

Considering the critical state, smart meters were installed to control groundwater overdrafts. The smart meters measured the water extraction rates and the power consumed and calculated the optimum water requirement. After initial hesitation and attending 130 informative meetings, the farmers accepted the proposal.

The following action steps were implemented as part of the master plan:

(a) The plan was implemented in three phases. In 2008, the first phase was devoted to installing and calibrating reading counters (meters). The amount of water extraction was not restricted in this phase. Just the rate of extraction was measured.

(b) The second phase in 2015 defined the permissible water extraction rates for wells based on license. During water shortage, extra charges were levied, but this was limited to one period and per cropping and harvesting requirements.

(c) This played a significant role in convincing farmers to adopt new cultivation patterns according to the available water. At the end of this phase, the beneficiaries demanded the installation of meters on all wells and monitored the overall plan's enforcement. The successful implementation led to the project's advancement in the whole province.

(d) In the first stage, smart meters were installed on 1,917 agricultural wells and in the second phase, on 1,331 active wells in (household) drinking, industrial, and service sectors. In the final phase, the installation of meters (counters) was continued for monitoring and management purposes.

(e) In the third phase, enforced in 2015-2016, the amount of harvest was controlled, and extra charges were eliminated. The main direction was to modify the cultivation pattern without compromising the farmers' income.

The allocation of groundwater to cultivate market-garden products was stopped, and crops with low water requirements were promoted, such as rapeseed. This increased farmers' revenue and influenced crop production choices to achieve sustainability. The rate of extracted water from the wells also decreased, and the water deficit in 2016-2017 fell to 135 MCM.

The farmer's responsibility to manage water increased surface area covered with new irrigation. The land under the annual coverage of modern irrigation increased from 1,402 ha in 2015 to 1,486 in 2016 and 10,024 ha in 2017. This showed a 57% increase in lands equipped with new smart meters for water and electricity.

4.6.10 Water-Saving by Systematic Water Intervals Method in a Basin Plan

Submitted By: Mohammad Ebrahim Yakhekeshi and Amrollah Barari Siavoshkolace (2016)

One of the major concerns of *Mazandaran* farmers in Iran is drought and water scarcity, especially in the dry season. The issue was historically handled by diverting more than 17,000 ha of lands to construct 800 cut-offs (*Abbandan*). Moreover, the development of cultivated lands in recent years led to decreased runoff, reduced water supply in dams, and higher cut-offs. The growing trend of rice re-cultivation of high-yielding and unripe rice varieties added to the current water scarcity.

The Mazandaran Regional Water Authority introduced water interval plans in big water bodies to address these concerns and issues. It was performed in a water-scarce village for a limited period as an experiment in contrast to the traditional approach. As the volume of precipitation and runoff in important rivers decreased between 20 to 40%, the authorities developed scientific measures after repeated meetings with the farmers for local wisdom and the data analysis reports. The implemented strategic plan was as follows:

The water interval plan assessed the water needs and availability by analysing data such as existing storage, precipitation, runoff, forecast on precipitation, agricultural preparedness, water needs, and identified vulnerable areas.

As a pre-implementation measure, the water crisis committee constituted three-level authorities (National, Regional, and administrative boundary) which held meetings with water users, pooled their experiences, and constructed temporary structures for water interval plans. After multiple repairs, the plan was functional, dredging of the canals/water distribution systems, compiling the irrigation schedule requirements, and recharging the groundwater aquifer by allowing river water flow during the non-cultivable season. During the implementation phase, the performance of the pilot plan was reviewed in meetings with broadcasting reports, and disputes were resolved, if any. Water interval plans were devised for two-time frames, 48 hrs and 72 hrs. Determination of suitable coefficients in water division was done (6 coefficients for 48-hr water intervals and 10 coefficients for 72-hr water intervals). The water application area was divided into three areas as top, middle, and lower part of the dam. Priority of water release was from tail end to upper part.

The applied management technique reduced the water usage in paddy fields from 10,000 m^3/ha to <7,000 m^3/ha. About 400 MCM water was saved with the technique. Labour work or the time spent by farmers on the ground was also reduced. Damages were reduced from 20% in similar years to less than 2% in the execution year itself. Arable crop production increased from 40,000 to 100,000 tons due to the plan's effectiveness. The presented plan can be further expanded by establishing regional associations, establishing new education courses in water management, and compiling the performance of the executed plans.

4.6.11 Participatory Water Management System in Golestan Province, Iran

Submitted By: Rahmatolla Kazeminejad (2016)

In Iran’s Golestan province, a participatory water management system aimed to promote the efficient use of water resources for irrigation and reduce water consumption was implemented in the *Tazehabad* region. The objective was to improve efficiency with the active participation of farmers, a mechanism that can be replicated in other areas. Activities were set to achieve tangible goals such as increasing the irrigated lands and efficiency upgrades in three parts: transmission, distribution, and water use.

The project cycle management methodology was used, and a logical framework of Project Design Matrix (PDM) and the plan of operation (PO) was created for implementation and monitoring. The decisions were taken with due consideration of the infrastructure and the climatic data in the presence of farmers. Facilitating and meta-facilitating techniques were used based on the community’s responses.

Activities such as data collection, farm plot certificates, certificates of irrigation network structures, low-cost methods of soil analysis, and measurement of water flow in canals were done by the farmers themselves. On the one hand, farmers were responsible for assessing water requirements and the amount needed for their farms; on the other hand, they became more familiar with the thrift-based systems in surface irrigation and started using water by turns. Simple irrigation techniques like land levelling were also introduced. The farmers and the community also managed other irrigation techniques such as furrow (leakage) and strips, irrigation programs, and strategies. Water management units comprising water users from all the channels were constituted and the administrative units provided technical support and good practices and monitored the implementation progress.

After the project’s successful completion in January 2013, the quantitative results showed that water efficiency reached 1.67 from 0.8 in pilot farms. In the last crop year (2013-2014), it nearly reached 1.17 in the whole of *Tazehabad*. Irrigation efficiency increased from 20 to 30% (for irrigation in width, length, and angle) to 40 - 60%. The irrigation area increased almost twice from 430 ha to 900 ha in one year. The established partnerships among stakeholders led to an exponential growth in the region to this extent that they rented their storage dam (reservoir) for fishery and resorted to alternative approaches like organic farming.

4.6.12 Optimized Consumption of Water in Paddy Fields

Submitted by: Mr. Seyed Jafar Bahari1 (2020)

A mixed irrigation methods technique was developed for rice cultivation in *Abbandan, Iran,* which had many benefits, including preventing and controlling various plant diseases, increasing plant tillering, providing oxygen to the plant's roots, and reducing water pumping costs (including fuel and pump maintenance costs).

To reduce water consumption in rice cultivation at various growth stages, a measuring cylinder and water meter were used to adjust the amount of water required by the plant at different times. Winter and spring rainfall (green water) and surface runoff were used to save water at puddling and ploughing in the initial land preparation stage. Scientific methods were also used to transplant paddy plots at the borders (to reduce percolation losses). In addition, some appropriate changes in tillage machines to improve soil water moisture content were conducted.

The land was disk ploughed in several stages in late fall or early winter. Periodic disk ploughing with high soil moisture improved soil compaction. A part of the hardpan layer was formed to prevent water penetration to the soil depth and caused minimum tillage in the next crop season. If the tillage depth was low, less water was used for transplanting, the soil was washed due to high winter rainfall and soil salinity was also reduced.

Appropriate changes were made in the structure of the tractor tire wheels (such as selecting the tire and its wheel arch, angle, treads distances, and height) for ploughing; the depth of puddling decreased from 25-35 cm to 12-15 cm, which saved water concerning puddling stage and also facilitated land leveling. The puddling operation was repeated several times to make the soil smaller and smaller.

After the puddling operation, the field's (earth) unevenness was removed to level the ground completely. The tailwater routes were blocked from the farm by covering the land with nylon so that water does not escape from the farm, and the border was closed with 12-15 m trans plantings.

A healthy nursery was prepared for transplanting bio-fertilizers which were used to keep the plants fresh. In the nursery, fewer nitrogen fertilizers were used to have healthy roots. This strengthened the seedlings in the land. Afterwards, water was used alternately for tillering. This also protected the rice from diseases and harmful gases such as methane and provided good oxygen to the rice roots.

During the initial stage of cluster formation, the water level in the field was brought to 5 to 7 cm for a week, and after this stage, continued periodic irrigation was practised until the emergence of clusters. From the time the clusters appeared until the end of flowering, the farm was kept flooded. After this stage, until the formation of the seed, the periodic irrigation continued.

The results showed that water consumption in paddy fields was reduced by 40% (the amount of water consumed for the local rice crop was 6,000 m^3/ha). It was observed that an optimal soil moisture level was obtained by a shallow depth of the tillering, puddling, and alternating irrigation without any problem in crop harvesting.

With this method, crop yield increased both in quantitative and qualitative aspects, crop per ha for *Tarom* cultivar (local rice), and *Shiroodi* cultivar (high yielding rice) were 7,200 and 12,000 kg/ha, respectively. On average, crop yields increased by 35 to 40% per ha.

All varieties of paddies can be irrigated with this technique and can reduce water consumption in large paddy areas. It also increased the water storage in the traditional reservoirs (Abbandan) in Iranian villages and provided favourable conditions for second cultivation (Raton or re-cultivation of rice) in paddy fields and fish farming.

4.7 IRAQ

4.7.1 Compost Effects on Soil Physical Properties and Plant Growth of Bamboo in Saline Soils

Submitted By: Nallah Abed Abbas (2013)

A pot experiment was conducted in a glasshouse at the Waite Campus of the University of Adelaide, Australia. Seedlings (10 cm high) of the tomato variety (*Lycopersicon esculentum* L.) were planted on 30 September 2011 for the composting experiment. The objective was to determine the effectiveness of adding compost to saline soil (E_c 1:5 3.9 dS/m) on improving soil physical properties and plant productivity of tomato, using two different water qualities (mains water, E_c 0.62 dS/m, and recycled water, E_c 1.5 dS/m).

The clay soil was collected from the Northern Adelaide Plains, blended, and steam sterilized before use to ensure that it was free of plant pathogens. Twenty white plastic 20-L buckets (inside dimensions: height= 38.5 cm, top diameter= 28.5 cm, bottom diameter= 24.5 cm) were lined at the bottom with 1 kg of stones covered by geotextile fabric to prevent blockage of drainage holes. Ten of these pots were then filled with 22 kg of soil, and the other ten pots were filled with 17 kg of soil. Finally, a mixture of 5 kg soil was mixed with 200 ml of compost (to simulate a rate of 30 m^3/ha) and added to the top of the soil. The experiment was laid out as a factorial randomized complete block design and lasted three months.

It was concluded that adding compost to the saline soil created favourable physical properties and plant growth. In addition, compost increased water use efficiency for plant production up to 15% when mains water was used and 10% when recycled water was applied. Furthermore, irrigated tomato yield with mains water increased by 38%, and recycled water increased by 24% when compost was added. The compost saved water by increasing water use efficiency for plants biomass for both recycled and mains-water, which positively reflected plant productivity. The compost improved the plant's production and soil's physical properties when recycled water was used. The experiment shows that adding compost to the soil can save water, especially in arid areas such as Iraq, by using recycled water as a supplementary source for irrigation. In the future, the research can be expanded on different types of soil, which was done on heavy clay soil. In addition, long-term research to evaluate the action of compost on improving soil physical properties can also be conducted. Different types of irrigation methods could lead to other results. The dose of compost used in this experiment was at a rate of 30 m^3/ha, so increasing doses through other experiments could improve the production of plant and water use efficiency. Studies on chemical and physical properties should be done to evaluate the nutrients and minerals released from different compost types.

This management technique can be introduced to farmer communities through lectures, spreading awareness, and explaining its benefits like water conservation and increased crop production.

4.8 PAKISTAN

4.8.1 Increasing Water Use Efficiency of Crop Production

Submitted By: Dr. Muhammad Akram Kahlown (2018)

Pakistan is an agrarian country. The agricultural productivity is low compared to that of developed countries. One of the major factors causing this low productivity is that the available land and water resources of the Indus Basin are not being utilized to their full potential. Rice and wheat are the major cereal crops grown in the summer and winter seasons on an area of about 2.46 and 8.22 Mha, respectively. These crops consume a big share of water available for agriculture. Moreover, the farmers generally apply irrigation water to un-levelled bunded units, resulting in long irrigation events, poor water uniformity, and over-irrigation.

A new management technique was developed to improve the farm's water use efficiency in such a situation. Trials were conducted on farmers' fields during 2002-2004 to evaluate the potential of rain-gun sprinkler irrigation for improving water use efficiency in rice and wheat cultivation. The technique was adopted in the *Potohar* plateau of Pakistan to provide supplemental irrigation to dryland farming.

During these studies, the irrigation water was applied at rates above and below the evapotranspiration (ET_c) requirements for rice and wheat crops. The water use efficiency of the crops grown under basin flooding was also monitored for comparison. Irrigation interval, amount, and uniformity greatly affected the water use efficiency and yield of rice and wheat crops.

Results showed that less irrigation water was needed when both rice and wheat were irrigated with rain-gun sprinklers and water use efficiency was 120% and 195% higher than for basin irrigation. Depending on the crop and the seasonal conditions, irrigation requirements can be as low as 26% of the water used in basin irrigation. Water use efficiency of rice and wheat were 0.55 and 3.95 kg/m^3 of water with sprinkler irrigation and 0.25 and 1.34 kg/m^3 with basin irrigation, respectively.

Benefit-cost analyses based on water saved indicated that investing in a rain-gun system to irrigate rice and wheat is a financially viable option. With this technique, the water use efficiency of wheat was five to six times as high as it is for rice, partly because temperatures and transpiration were lower during the winter wheat growing season. However, growing more wheat and less rice was not found feasible.

Studies on water use efficiencies of maize grown in the summer months were close to those of wheat in the winter because the growing season of the maize was shorter. Growing more maize and less rice during the summer months was a viable option for increasing grain production and producing more palatable fodder. However, energy costs become an additional deterrent to pressurized irrigation systems hindering their expansion in the Indus basin. These research outcomes were also coordinated with the Extension Service, and more trials were organized under different soil types and agro-climatic zones in the irrigated area of the basin.

4.8.2 Sustainable Agriculture: Aiming towards Conserving Water and Improving Livelihoods

Submitted By: WWF Pakistan (2011)

In Pakistan, the agriculture sector plays a vital role in economic development, employing approximately 42% of the country's population. The country's natural resources are under constant stress due to rapid population growth and environmentally unsustainable practices. Renewable freshwater resources are fast depleting and pushing Pakistan into the category of water-stressed countries. With a scant average annual rainfall of 240 mm, there are no readily available large freshwater sources. Considering the scenario, WWF-Pakistan implemented the Sustainable Agriculture Programme (SAP), focusing on the sustainable use of freshwater resources concerning agriculture, management, and conservation. SAP's projects are briefly discussed below:

(a) European Commission funded Thirsty Crops Project (ECTCP): The project aimed towards lowering the consumption of pesticides and water used in sugarcane and cotton production to increase/maintain the water quality and quantity. Target areas included farms in *Faisalabad* and *Bahawalpur Punjab*, Pakistan. It was implemented at a district level collaborating with the provincial and national governments.

(b) Pakistan Sustainable Cotton Initiative (PSCI): Since 2005, WWF-International, in collaboration with IKEA, has been implementing BMPs (Better Management Practices) for drought-resistant/tolerant cotton seed varieties, such as sowing techniques, soil conditioning techniques, and tillage operations. Farmers were trained to adopt BMPs to grow better quality cotton and decrease the use of agrochemicals. For instance, farmers performed Cotton Eco System Analysis (CESA) in cotton fields, identifying beneficial pests and insects every week. This training and awareness about pests and pesticides, irrigation, and fertility indicators led to optimized use of water and fertilizers, and homemade organic botanical extracts replaced the chemical/synthetic pesticides.

(c) Sugar Producer Support Initiative (SUSPSI): BMPs were implemented to conserve water quality and enhance the sugarcane industry's contribution to rural development. Furthermore, the Better Sugar Initiative (BSI) developed the metrical indicators. SUPSI also focused on developing direct collaboration between millers and farming communities, leading to an improved supply chain for a better economy and livelihood of communities. Environmental and social standards criteria set by SUPSI aimed to enhance collaboration among the sugar retailers, investors, traders, producers, and NGOs committed to sustainable sugar. SUPSI's main focus was to improve the efficient use of agricultural inputs, increase yields and sucrose recovery rates, eliminate the use of highly toxic pesticides and fertilizers, and restore environmental flows.

(d) WWF-P and Better Cotton Initiative: The Better Cotton Initiative (BCI) is a multistakeholder initiative to make cotton cultivation environmentally, economically, and socially sustainable in the mass market. A multistakeholder approach with multinationals such as IKEA and Marks & Spenser brand leveraged the commitment of global buyers towards cotton or cotton products and created a demand for "Better Cotton." WWF-Pakistan's vision for BCI was to reduce the impacts of conventional cotton cultivation using BMPs on the environment and improve the livelihoods of the farming communities.

This combined effort of the two organizations named Pakistan the first Better Cotton Qualified Country, with a 38% reduction in chemical fertilizer use, 32% reduction in pesticide and water use, and on average a 20% increased profit for BMP implementing farmers. Overall, the initiative created synergies for implementing BMPs, improved the livelihood of communities, emphasized education and awareness, and environmental sustainability of the resources.

4.8.3 Enhancing Water Productivity through Improving Irrigation Efficiencies at Farm Level

Submitted By: Chaudhary Mohammad Ashraf (2012)

Pakistan's Punjab province's tertiary level irrigation system comprises about 58,000 watercourses. Different studies have revealed that a major portion (about 40%) of the water delivered at the canal outlet (mogha) is wasted before reaching the fields because of poor maintenance and century-old community watercourses. Moreover, a substantial (20 to 25%) amount of irrigation water is wasted during its application to crops due to uneven fields and poor farm layouts. Uncontrolled surface flooding is the most common irrigation method practised by farmers in the country, which has no more than 50% efficiency. To address these challenges, several on-farm water management (OFWM) initiatives were implemented during the last decade to improve the tertiary irrigation system by enhancing conveyance, application, and water use efficiencies.

A mega initiative called the National Program for Improvement of Watercourses (NPIW) was launched in 2004 through a community-driven implementation approach. The community channels were rebuilt according to the engineering design and participation of the Water Users Association (WUA). Project Impact Evaluation Study

(PIES) affirmed that the intervention was a highly cost-effective option for saving water and improving farmgate water availability.

Under NPIW, LASER technology for precision land levelling was introduced. Roughly 2,500 LASER land levelling units were provided to the farmers and service providers. The initiative proved to be highly beneficial in accelerating the pace of technology adoption resulting in a significant impact on water productivity showcased in the following outcomes:

(a) Saving in irrigation time from 25.1 to 32.1%

(b) Increase in the irrigated area by 34.5 to 42.0 %

(c) Improvement in crop yields from 10.7 to 12.9 %

(d) Reduction in farm wasteland by 2.10 %

Drip and sprinkler irrigation was also implemented as part of the initiative. It exhibited promising impacts against conventional irrigation practices, including water-saving of about 50%. It was proved highly effective as cotton yield increased to 0.753 ton/ha with an average of 0.453 ton/ha against the 0.243 ton/ha average in the area. The intervention promoted cash crop production on sand dunes without land levelling for oilseeds, onions, vegetables in tunnels, maize, and watermelon. Drip and sprinkle irrigation resulted in 27 MCM of saved irrigation water.

Overall, OFWM techniques enhanced irrigation efficiencies at the farm level and saved about 13,000 MCM of water. Saved water from watercourse improvement was used to expand irrigated agriculture by increasing cropped area in watercourse commands that were left fallow earlier because of water shortage.

In terms of expansion, improving the remaining 15,000 watercourses would further result in substantial water savings. LASER land levelling in conjunction with micro-irrigation techniques can additionally save about 27 MCM of irrigation water. The Punjab Irrigated Agriculture Productivity Improvement Project (PIPIP) envisages upgrading and developing 9,000 unimproved and partially improved irrigation schemes in the region.

4.9 REPUBLIC OF KOREA

4.9.1 Development of Smart Water Management System using IoT Technology

Submitted By: Oh Changjo (2018)

Agricultural uses are approximately 48% of the total annual water use in South Korea. While approximately 70% of the annual rainfall is received during the summer season, most of the agricultural water is utilized from May to June. Therefore, irrigation facilities using reservoirs, canals, and pumps were installed to manage water on the farms efficiently. The supply of agricultural water also varies from season to season due to climate factors, regional topographies, river characteristics, and the water level. Over time, the imbalance between supply and demand undermined efficiency in supply and management. In such a situation, scientific decision support systems became necessary to resolve water efficiency problems and maintain long-term sustainability.

South Korea modernized its reservoir irrigation system through the effective use of information and communication technology (ICT) for periodic monitoring and analysis of the collected data. ICT informed decision makers and assisted in operation and management tasks in the irrigation system. The upgraded system improved irrigation efficiencies and increased productivity by providing refined irrigation scheduling plans for different crops for different seasons.

A web-based measurement system was developed with a standard model to calculate the optimal amount of water supplied to the respective area and provide relevant information. The system also created a real-time evaluation of the efficiency of water used, better allocation of water resources, and improved water services to farmers.

Automatic water gauges were installed at the Dongjin River Basin's main and branch irrigation canals. The water levels were monitored and calibrated, and the irrigation water supply and irrigation efficiencies were calculated from 2012. An irrigation model considering intermittent irrigation was developed to compare the estimated irrigation demands with the actual supplies to develop decision-making and demand strategies. The optimal water supply curve based on the precipitation scenario and the previous water supply curve developed through monitoring and modelling were also suggested. A risk-based decision support system (DSS) for the operation and management of the agricultural water supply was developed and evaluated. The smart water management system was applied to a total area of 16,567 ha, consisting of 16 canals and branch lines (59km). It was difficult to secure enough water to be used for irrigation through the local streams or rivers alone. Therefore, an operation method of classifying the upstream and downstream by the day of the week was developed.

Application on the site consisted of major facilities (reservoirs, water pumping, distribution systems, and weirs). 141 measurement facilities were installed at the beginning and the end of the regional stream as well as at water gates to prevent natural disasters and measure rainfall, water flow, and water levels to capture images. This system allowed optimum management of irrigation water. The cutting-edge IoT technology in measurement systems on sites allowed real-time information to be delivered regardless of time or space to the decision-maker. The smart water management system was based on the web or mobile network to receive real-time data from the on-site measurement device and the water systems chart. Information such as the amount of rainfall, water levels, river levels, and images was provided, along with the status of the water supplied through each branch of the water source along with warnings for abnormal water levels.

Unlike the existing SCADA system, this smart management technique formed an autonomous network based on the internet and enabled wireless communication making remote monitoring possible. This technique can be further replicated in other basins for efficient water management.

Figure 4.39 Dongjin River Basin

4.10 SOUTH AFRICA

4.10.1 Water Distribution Management at the Vaalharts Irrigation Scheme

Submitted By: Mr. Kobus Harbron (2010)

The Vaalharts irrigation scheme is situated at the confluence of the Harts and Vaal rivers on the border between the Northwest and the Northern Cape provinces in South Africa. It is the largest irrigation scheme in the country, with a scheduled area of 29,181 ha. The scheme consists of a network of canals covering more than 100 km supplying water to about 1,873 abstraction points through pressure regulating sluices.

Vaalharts water distribution practices suffered from the limitations of a manual system, including higher labour force requirements, calculation/estimation errors, indirect method of estimation of releases, difficulty in incorporating the changes in demand, individual's experience, and information collation in the distribution management making the water use efficiency reports time consuming and inaccurate.

The weekly water distribution management practices at Vaalharts Water were very labour-intensive. Moreover, preventing water losses and maintaining a good rapport with farmers was becoming increasingly difficult for the management. These limitations were overcome by developing and introducing a computerized system in the form of the Water Administration System (WAS).

Water orders were captured directly by water control officers, calculation errors were eliminated, water balances were updated daily, digitized systems replaced conventional charts, and release volumes were computed weekly instead of earlier monthly volumes. The water distribution sheets were modified quickly, incorporating the changes in the demand, and water use efficiency reports were generated automatically with the WAS. The computer system facilitated the water control officers to carry out more inspections and minor repairs like canal leakages and breakages, which were easily monitored while maintaining clients' timelines.

Productivity vastly improved with reliable water use efficiency reports produced using WAS. The water control officers developed a positive attitude as their administrative responsibilities were reduced and they could invest more time in strategic planning. Water losses on the scheme decreased from 32% to 26.7% in a single year due to WAS's efficient mechanisms.

The implementation of the WAS program made water-savings at Vaalharts Irrigation scheme sustainable with the potential for future advancements. As the proficiency and knowledge of the personnel increased, the accuracy of supplying the correct amount of water to the right place at the right time improved, and more water was saved.

Figure 4.40 WAS mechanisms and products

Sharing close ties with Vaalharts irrigation scheme, Taung irrigation scheme was also recommended to adopt a similar approach under the guidance and supervision of the team. The use of modern tools and Information Technology could improvise water management practices in terms of computations as well as infrastructure maintenance ensuring easy experience sharing and a seamless knowledge transfer.

4.10.2 The Implementation of the Water Administration System (WAS) at Lower Olifants River Water User Association

Submitted By: Johan Matthee (year)

Lower Olifants River Water Users Association (LORWUA) is one of the biggest irrigation schemes in South Africa that delivers water on demand to over 1,000 abstraction points on a canal network to irrigate a total area of 9,510 ha. Water is ordered and released weekly from the Clan William dam into the Bullshoek dam and then into a 90-km main canal with secondary canals for distribution.

A computerized system called Water Administration System (WAS) was implemented to manage and supply the correct water quantity to the right place at the right time with minimum water losses within the limitations of the Lower Olifants River irrigation scheme system. Given the size of the scheme and the large number of farmers involved, it was a daunting task for the authorities. The association completely replaced the manual water distribution system with an automated system. WAS was implemented at LORWUA in 1997 for the first time, and it was initially only used to manage over a thousand accounts of their farmers monthly.

Water was delivered to individual farms through pressure-regulated sluices that were manually operated by water control personnel. The opening and closing times of the sluices specified on weekly water distribution sheets were generated using the Water Administration System (WAS). Peak water demands at the end of the grape season placed enormous stress on their over-allocated canal network which, in turn, made effective water distribution management crucial. These challenges were overcome by the successful implementation of the WAS. This included the installation of the required computer hardware and the training of water control personnel to operate the WAS effectively. WAS is an integrated management tool for irrigation schemes that deliver water on demand through canal networks, pipelines, and rivers.

WAS consists of nine modules that are integrated into a single program and can be used on a single PC or a multi-user environment. These modules can be implemented partially or, depending on the requirements of the specific scheme or office. The nine modules are - Administration module, Water order module, measured data module, Water release module, Report module, Accounts module, Crop water use module, Dam information module, and a bulk SMS module. The WAS is currently in use at all the major irrigation schemes across South Africa and it manages an irrigated area of more than 142,000 ha including 9,500 farmers.

The main benefits of using WAS are:

(a) Minimizing water distribution losses
(b) Management of water quota allocations and water usage per farmer
(c) Uploading and downloading water orders using the internet
(d) Availability of extensive water reports and graphs at farm and scheme level
(e) Increased productivity of scheme management personnel
(f) An integrated debit accounting system that improves debt management
(g) Availability of an integrated bulk SMS system to communicate water ordered and water use information to farmers.
(h) Improvement of the overall water administration management on irrigation schemes.

With the implementation of the WAS program, LORWUA managed to decrease the losses from 35% to 25% which is equivalent to 8.5 MCM per year. This saving is equivalent to an additional 696 ha that can be irrigated additionally per year given that the full water quota at LORWUA is 12,200 m^3/ha. In 2002 the functionality of the water distribution modules of the WAS was expanded to include their specific methods and procedures. Using the WAS effectively makes water-saving sustainable in the long run. A computerized water management system like the WAS prevents human errors that can lead to potentially huge water losses, but it still needs a dedicated individual for water management principles. Feedback from the WAS users at training courses indicates that it is considered impossible to manage irrigation schemes without the use of the WAS after converting.

4.11 SPAIN

4.11.1 Integrated Urban Water Reclamation and Reuse System, Murcia Region, Spain

Submitted By: Manuel Albacete Carreira (2012)

The Segura River is the main water source for irrigation in the Murcia region of Spain. The mean annual natural run-off for the Segura Basin amounts to 803 MCM/year, with an exceptionally low average water availability of 500 m^3/person/year. The basin suffered from a structural water deficit along with a lack of supply assurance, even though the possibilities for regulation, saving, reuse, and efficient use of water resources have been pushed to the limits through different actions for many years. All aspects related to water management have been particularly conditioned by the “structural water deficit.” Considering this situation, a New System for Urban Wastewater Reclamation and Reuse was developed.

This new system was established and enacted by the Regional Government of Murcia and was implemented by creating the Entity for Sanitation and Treatment (ESAMUR) in the year 2002 and by the development of the General Plan for Sanitation and Treatment (PGS) for 2001-2010. This management system proved efficient and fulfilled all the goals set in its design phase. The General Plan for Sanitation was formally approved in 2001. During its implementation, around 90 wastewater treatment plants (WWTP) were built or refurbished, along with a complete network of collectors and pumping stations, which achieved the recovery and treatment of 98% of urban and industrial wastewater.

The Entity for Sanitation and Treatment (ESAMUR), responsible for managing, operating, and maintaining the new system, started operation in June 2002. The Sanitation Fee, a purpose-determined regional fee, ensured the new system's economic sustainability. A single tariff was applied throughout the whole region, differentiating between domestic and industrial discharges. The industrial fee applied the “polluter pays” principle, considering coefficients that penalized the polluting discharges. Detailed analytic monitoring was carried out for quantifying water quality (influent and effluent) at each treatment plant.

A decade after the start of this new management system, the results were satisfactory not only for water quality, water-saving, and efficient use but also for economic sustainability and efficiency ratios. There was a 13% increase in available water resources. The objective of having higher water availability of an appropriate quality for reuse in agriculture was achieved. In 2010, an estimated 100 MCM was directly or indirectly reused in the Segura River or its tributaries, which amounted to 90% of the total volume of the treated wastewater.

General System for Urban Wastewater Reclamation and Reuse in the Murcia Region is an example of modern Systems Engineering. It has solved complex problems such as the environmental restoration of a great river within a structural water deficit scenario and the integrated management of water scarcity. The high-level legal, administrative, managerial, and technological regulations that framed the System for Urban Wastewater Reclamation and Reuse can be extrapolated to other circumstances and locations. Moreover, the valuable experience gained can be used in other arid regions facing similar problems. Furthermore, monitoring these activities led to research and development on wastewater treatments, using biogas energy, and organic sludge, published in research papers and journals.

4.12 THAILAND

4.12.1 Innovation, Implementation, and Extension of the Water-saving Integrated Smart Farming – AWDI Technique in Thailand

Submitted By: Mr. Va-Son Boonkird and Dr. Watchara Suiadee (2016)

In 2004, Japan and other countries, including Thailand, formed a new body named the International Network for Water and Ecosystem in Paddy Fields (INWEPF). The broad goal of INWEPF was to increase rice yield in a sustainable and ecologically sound manner. In August of 2012, the best practices of the Alternate Wet and Dry Irrigation (AWDI) technique were incorporated with Smart Farming innovations as a new model. The model promoted the AWDI technique while managing practicalities in the real world, such as minimized labour intensity with maximum water-saving. Out of four wet and dry periods, only two wet and dry periods were used, resulting in 20-33% water-saving in paddy production.

Under this adapted method, rice is submerged to a depth of 5 cm above ground level until the pollinated plant starts to bloom, then water depth is increased to 7-10 cm above the ground. In the next stage, when the plant is 35-45 days old, the cultivation area is not irrigated for 14 days. This period is referred to as the first dry period, and the water level in the paddy field is expected to drop to 10-15 cm below ground level. Then the ground gets dry, and cracks appear on the surface. After the first dry period, the area is irrigated again until the water level reaches 7-10 cm above the ground. This wet period continues until the rice plant is 60-65 days old. Then begins the 14 days of the second dry period following the same procedure as the first dry period. After the second dry period, the field is once again irrigated to 7-10 cm above-ground and this level is maintained until harvest, approximately for another 40 days. During the two dry periods, the plant becomes stressed and struggles for survival, and therefore changing both the root structure and the above-ground parts of the plant leads to increased yields whilst at the same time saving a significant amount of irrigation water.

Against the conventional four alternate wet and dry periods which is labour intensive, the only two-period cycle was practised. The Integrated Smart Farming - AWDI technique can help manage modern world challenges like increasing demand, water scarcity, and the negative effects of chemical fertilizers. The technique reduces irrigation water use by 1/3 and cuts the need for chemical fertilizers by 70-100%. Overall, this method can cut the cultivation budget by half and increase the yield simultaneously. Usually, a yield of 5000 kg/ha would be expected, but it can increase by 25% to 6,250 kg/ha under this technique.

Figure 4.41 Integrated Smart Farming- AWDI Technique

Under the Integrated Smart Farming - AWDI technique, 23% less water, 67% less initial seed, 38% less fertilizer, and 50% less pesticide are required. The time required also reduces by 19% while the yield increases, increasing the economic efficiency of cultivation.

In Thailand 1.6 Mha of dry season, paddy is fed by more than 12,500 MCM of irrigation water which can be saved substantially using this technique. If the Integrated Smart Farming - AWDI technique is applied throughout Thailand, it is expected that irrigation water-saving during the dry season can be increased by 33%, which is more than 4,100 Mha. This has the potential to further expand the irrigated dry season paddy field area from 1.6 to 2.16 Mha. Additionally, the technique reduces the emission of greenhouse gas (GHGs), enabling Thailand to fulfil its legal obligations to the United Nations Framework Convention on Climate Change.

The innovation demonstrated that knowledge dissemination and technology go hand in hand to achieve water-saving at a large scale.

4.13 TURKEY

4.13.1 Water-Saving through Rehabilitation of Irrigation Projects in Turkey

Submitted By: Ali Kilig (2013)

In Turkey, private construction companies carry out irrigation projects under the management of State Hydraulic Works (Devlet Su İşleri - DSİ), a state foundation responsible for managing the country's water resources. While Turkey continues making major investments in the irrigation infrastructure by opening new irrigation areas, there is an equal focus on increasing water use efficiency for saving water through system improvement and managerial interventions.

The new strategy of DSİ in irrigation is aimed to modernize the irrigation infrastructure with buried pipe networks and techniques such as pressurized sprinkler or drip irrigation. Rehabilitation of existing irrigation projects by utilizing advanced irrigation methods and water conveying techniques was an institutional strategy to increase the crop yield by using less water and, in turn, increasing farmers' incomes. Under this strategy, the Mamasın Irrigation Project, under operation since 1964, was rehabilitated. Initially, water was transmitted through lined open channels and 2,208 wells to meet local water demands leading to overexploitation and soil salinization.

The first activity undertaken in the rehabilitation process was to investigate the irrigation area and conduct a feasibility study. The study detected that farming in some parts of the 23,640 ha of irrigation area was not sustainable due to structural concerns ever since 1964. Besides structures, losses in open channels due to evaporation and leakage, uncontrolled irrigation, and dry climate periods decreased the irrigation rate in the region down to 70%. Hydrologic and hydraulic calculations within the feasibility study envisaged the new irrigation area to be 23,000 ha after excluding or including some lands.

Therefore, the surface irrigation method on lined open channels was replaced by a pressurized drip/sprinkler irrigation method through a buried pipe network constituted of HDPE (High-Density Polyethylene) and GRP (Glass Reinforced Pipe) pipes. In the rehabilitation model, water was directly taken from the bottom outlet of Mamasın Dam and transmitted to the irrigation network by the main pipeline passing through the middle of the irrigation area without following the old main open channel route. Delivery of water directly from the bottom outlet of the dam enabled the delivery of high-pressure water throughout the irrigation area. As a result, 50.6 MCM of water was saved per year in the Mamasın irrigation area.

The future scope of this innovation is immense. The conversion of the primitive irrigation methods into modern irrigation through the rehabilitation (or renewal) of existing projects like the case of the Mamasın Project can be further expanded by more investments, as per DSİ's mandate. Moreover, the modernization works can be replicated in other countries as well.

4.13.2 Collective Pressurised Irrigation Project

Submitted By: Omer Lutfi Aksu (2012)

The Collective Pressurised Irrigation technique replaced the traditional open canal system in a 250-ha agricultural region in *Üzümlü* district of *Erzincan,* Turkey to achieve water use efficiency.

A pressure piped irrigation system is a network installation consisting of pipes, fittings, and other devices properly designed and installed to supply water under pressure from the source to the irrigable area. The pipelines that convey and distribute the irrigation water to the individual plots are usually buried and protected from farming operations and traffic hazards. Off-take hydrants are located at various spots according to the planned layout.

Under this project, the farmers used sprinklers and drip irrigation on their fields. The project area consisted of 230 parcels with 100 parcels of vegetable fields (drip irrigation), 80 parcels of fruit trees (drip irrigation), 40 parcels of cereals (irrigation canal), and 30 parcels of sugar beet (sprinkler irrigation). The old water distribution network was replaced with high-pressure PVC pipes and remote-controlled valve units (hydrants) for all the parcels in the field. The piped irrigation water supply system turned out to be an effective solution for achieving real water savings by providing high-pressure supply to horticulture areas.

Water was saved through reduced seepage and reduced evaporation from open channels. The cost and energy required to install piped system were covered by yield improvements. Additionally, there were environmental benefits like reduced greenhouse gas emissions and saline groundwater recharge. Surface irrigation had a water loss rate of 35% - 60%, whereas in sprinkler and drip irrigation water loss was less than 5%.

The project was demonstrated in regional seminars and the regional media. Technical excursions were also organized for interested farmers to disseminate the knowledge. In the first expansion plan, the project was implemented in 300 ha farmland in Üzümlü. Furthermore, Altınbaşak and Karakaya villages also allocated 350 ha of land for the pressurized collective irrigation system. The application of these improved irrigation methods and techniques on small farms expanded rapidly due to the increasing demand for higher irrigation efficiency.

4.14 UNITED STATES OF AMERICA

4.14.1 The Willow Creek Piping Project

Submitted By: Mr. Jerry Erstrom (2011)

Willow Creek basin is adjacent to Willow Creek and the Malheur River in Vale Oregon Irrigation District, USA. Earlier, the irrigation water was delivered to users from the main canal through a complex network of open earthen ditches, established in the 1930s. These open canals dealt with increasing concerns associated with breaches as well as human and animal safety. They also substantially increased operation and maintenance costs.

To manage the situation, the Willow Creek Piping Project addressed 35,000 acres (14,164 ha) in the agricultural area and simultaneously worked on water quality and water conservation concerns. Piping irrigation laterals facilitated on-farm conversion to sprinklers, reduced the need for hydro-power, tillage, and fuel usage, conserved water, improved fish habitat, and benefitted the local economy.

Some of the major transformations in the Willow Creek Piping Project are listed below:

(a) The piped irrigation virtually eliminated conveyance losses from seepage and evaporation from the open-ditch delivery system and improved water use efficiency on the farm.

(b) The pressurized system made switching from flood irrigation to sprinkler irrigation easier, more cost-effective and reduced the need for additional power.

(c) Sprinklers improved the irrigation application efficiency, reduced tillage needed for crop production, and decreased crop consumptive use.

(d) Other on-farm conservation methods included pump back systems which captured the irrigation runoff from crop fields and enabled multiple re-uses of irrigation water.

(e) Piped irrigation system provided gravity pressurized water to irrigators and decreased power costs by reducing or eliminating the need to operate irrigation pumps. It improved reliability, control, and consistency of water delivery and measurement.

(f) Reduced operations and maintenance requirements and created opportunities for small "low-head" hydro-power facilities

(g) Ultimately, it utilized irrigation water more effectively without increasing consumption.

Before the implementation of the Willow Creek Piping Project, a significant amount of water was lost from seepage and evaporation, especially at the beginning of the five to seven-month irrigation season when the canals were dry.

Calculations from the Vale Oregon Irrigation District showed that the first irrigation month's water loss averaged more than 90% before the piping project and rarely dropped below 30%. These issues were exacerbated in years when runoff reached below normal levels. In the high-desert region, the average rainfall was 10 inches per year. In low water years, the irrigation district did not receive sufficient water to meet all crop demands.

However, under the Willow Creek Piping Project, simply placing piping and burying open laterals prevented all water loss virtually from seepage and evaporation and enabled efficient delivery quantities and measurement. The piping project added USD 6.5 million to the state and federal grants funds to assist local farmers and ranchers in implementing better management practices that protect natural resources, conserve water and improve the water quality in rivers and streams. This project directly provided employment and opportunities for local businesses. In addition, yield increased due to efficient sprinkler irrigation and increased revenues to producers, which in turn helped the local economies of Vale and Ontario. These benefits lasted more than the lifetime of the project.

Willow Creek Piping Project essentially replaced the open canal conveyance system with piped irrigation system. This technique can be adopted globally as a water-saving measure. It leads to water conservation and promotes environmental sustainability and reduces the dependency on electricity and fossil fuel requirements.

5 EMERGING GLOBAL TRENDS IN INNOVATIONS FOR AGRICULTURAL WATER MANAGEMENT

Water enables agricultural production, but agriculture equally impacts water balance and quality. With the advent of hybrid crop seeds in the 1960s and 1970s, water consumption in agriculture increased rapidly, and it now accounts for 70-80% of freshwater withdrawal globally *(and an even higher share of “consumptive water use” due to the evapotranspiration of crops)*. Globally, climate change, rapid urbanization, growing inter-sectoral conflicts further exacerbate these issues. The unpredictable weather conditions are causing periodic drought and flood-related damages. Today's primary challenge is developing better technologies and sustainable practices to manage the water resources to meet growing demands for food production, drinking water extraction, safe working, living, and recreating and maintaining biodiversity.

Agriculture is a significant employment provider, mainly rural employment, ranging from 50 to 90% in some developing countries. Due to climate change, food security, flood-and-drought cycle, many rural households bear the brunt. A*gricultural water management faces some constraints like inadequate policies, infrastructural and institutional under-performance, capacity building woes, and restricted access to finance. Another concern is the lack of collective functioning of public and private institutions- ministries, basin authorities, irrigation practitioners, water users’ associations, farmers, and the community.*

Traditionally, capital-intensive schemes were promoted with a narrow focus on participatory practices and diverse social and environmental implications. Agricultural policies couldn’t fully realize the true potential of small-scale irrigation innovations requiring financing, which further hindered positive developments in the sector. *Moreover, trust deficit within the community, private sector institutions, and the government sector slowed down the progress and adversely affected the maintenance of irrigation and drainage systems.*

Given the existing constraints above, the agricultural water management sector today is currently in the process of repositioning itself towards modern and sustainable service provision. An integrated approach to build upon existing infrastructure, historical knowledge, and scientific evidence where all relevant stakeholders work in conjunction. It proposes a singular water approach to building resilient water services and sustaining water resources while managing risks related to broader social and economic water-related impacts. This includes transforming governance and service provision, supporting watershed management, and greening the sector and can be achieved by providing improved incentives for innovation, reforms, and accountability.

Creating synergy between agriculture and water policies and encouraging increased investments from public and private sources for sustainable development of irrigation and drainage are ICID’s prime focus areas. As farmers are at the core of agricultural water use and the principal stakeholders, ICID promotes Participatory Irrigation Management (PIM) and Management Transfer (MT) to enhance the performance of irrigation schemes.

ICID network, through its Vision 2030, is working tirelessly to mitigate the impacts of adverse conditions to develop the water sector resilience for providing a water-secure world free of hunger and poverty. ICID Vision 2030 outlines specific objectives including improving crop productivity while preserving water and energy, policy recommendations and best practices in agriculture, fluid exchange of knowledge among diverse stakeholders, cross-disciplinary and inter-sectoral engagement, research and innovation in the field practices, and overall capacity building. Different mechanisms may be needed to achieve the set objectives in specific contexts, considering the vastly diverse nature of institutions' geographical, political, and socio-economic fabric globally. There are both external and internal challenges faced by the institutions responsible for agricultural water management (AWM) and their stakeholders involved at different levels, i.e., global, national, regional, or local; and their role and functionality and related institutional development processes must be developed to realize the UN-SDGs and ICID Vision 2030.

ICID’s WatSave Awards initiative addresses these concerns by promoting innovations in technology and management that can be replicated globally for sustainable agricultural water management.

The idea is to create a platform presenting different innovative approaches to develop technologies and locally responsive AWM practices that address contexts involving diverse institutions, traditional researchers, young AWM professionals, and intended beneficiaries such as farmers and their water-sharing groups or cooperatives. While water-saving technologies and AWM are indeed critical to the emerging global problem-solution trends, the need for evidence-based water policy development and supporting roles of government, private sector, and non-governmental organizations at various levels are equally important in replicating, adapting, and promoting a water-conscious culture in the human societies around the world. In this regard, ICID Awards identify solutions that can be put in wider perspectives of agricultural and rural development in many parts of the world.

To preserve the environment and promote social equity, ICID gradually expanded its focus from technical issues to include other related disciplines such as environment, socio-economic issues, capacity building, and sustainable rural development, recognizing and at the same time appreciating the complexities of sustainable development of agricultural water resources.

A broad review of the ICID WatSave Awards nominations innovations and since 2009-2020 unveiled some emerging themes in the AWM sector.

(a) Agricultural Water Management is no exception to the global surge of technological solutions and IoT (Internet of Things) taking over conventional ideas. Automated solutions and app-based monitoring have witnessed a never seen pace in almost all parts of the world. Everything from crop selection, irrigation scheduling, soil moisture, weather forecast, water storage to water distribution can now be managed using technology in real-time. It is just a matter of time when globally the agricultural systems will be managed automatically and increase water use efficiency.

(b) Micro-irrigation techniques like sprinkler and drip irrigation have shown excellent results in all soil types, topographies, climatic conditions, and crops worldwide. These save water and lead to increased quality and higher yields. Micro-irrigation techniques are also implemented in conjunction with other water-saving practices creating fulfilling results. For instance, using computer-controlled drip "fertigation" (applying fertilizer with the irrigation water) economizes water and fertilizer use, and prevents soil salinization and ground-water pollution.

(c) Native and traditional agricultural practices are evolved, in harmony with the local agro-ecological realities. Even though economic realities play an essential role in selecting irrigation practices and the choice of crops sown, an increased focus on developing region-specific practices has been observed.

(d) New agronomic practices are innovated in almost all parts of the world to increase water productivity and yield quality and quantity. Innovations like raised bed planting, ridge-furrow sowing method, subsurface irrigation, and precision farming are gaining tandem and have been implemented in different climatic zones. A shift in the production of water-hungry crops to water extensive crops is also seen.

(e) Agricultural water conservation innovative practices have seen a boom in the last decade. Rain-water harvesting, capturing local runoff, reducing evaporative water loss, and floodwater retaining measures are some of the few methods which are extensively used, especially in dryland extensive agriculture, and within closed environments (using "desert greenhouses").

Some of the recently emerged water conservation and innovation practices can redefine the irrigation space by increasing productivity and efficiency, they are discussed below:

(a) Capturing and Saving Water: Many farms rely on municipal water or wells (groundwater), while some use ponds to capture and store rainfall for use throughout the year. Properly managed ponds are the new water source that can also create local wildlife habitat. Another revolutionary method is dry farming which doesn’t require irrigation and relies on soil moisture to produce its crops. Special tilling practices and careful attention to microclimates are essential.

(b) Drought-Tolerant and Cover Crops: Growing crops appropriate to the region’s climate has become the new policy. Crop species native to arid regions are naturally drought-tolerant, while other crop varieties can be selected over time for their low water needs. On the other hand, cover crops can be planted to protect soil that would otherwise go bare. These crops reduce weeds and increase soil fertility, allowing water to penetrate the soil and improve its water-holding capacity easily.

(c) Rotational Grazing: Rotational grazing is a process in which livestock are moved between fields to help promote pasture regrowth. Good grazing management increases the fields’ water absorption and decreases water runoff, making pastures more drought resistant. Increased soil organic matter and better forage cover are also water-saving benefits of rotational grazing.

(d) Conservation tillage uses specialized plows or other elements that partially till the soil but leave at least 30% of vegetative crop residue on the surface. Such practices can help to increase water absorption and reduce evaporation, erosion, and compaction.

Water accounting and delivery mechanisms encountered a 360º shift in the last few years. There is a growing emphasis on intelligent systems based on remote sensors, real-time data collection, GIS analysis, and quicker and insightful online communication that informs decision making and creates high-efficiency mechanisms for water and nutrients. These developments made the long-debated water pricing model more structured and adaptable. In some cases, water pricing has induced farmers to adopt appropriate practices for conserving water.

Irrigation infrastructure has widened its scope over the years from the provision of technical equipment and designing to retaining the nutritional efficiency of the soil as well as the crops, sustainability, and inter-changeability. Agricultural extension services, knowledge dissemination, and capacity building about irrigation infrastructure have also developed dramatically.

Decision-making and governance transformed over the years within the irrigation landscape to accommodate multi-disciplinary perspectives and multi-stakeholder participation. Inclusive community-based decision-making and participatory irrigation management are practised in almost every innovation. It is important to acknowledge that accountability and implications of the decisions made are gaining attention within the water sector.

Research and development have evolved rapidly within the agricultural water management domain. Technology-based solutions, irrigation, and infrastructure developments, management practices are continuously updated and restructured to combat against the concurrent challenges of climate change, increased population, water allocation conflicts, and ultimately the sustainable use of water. However, there is a need for more investments in research globally.

5.1 ICID WATSAVE AWARD INNOVATIONS

Based on the recent developments and, more specifically, the innovations presented to and by ICID WatSave Award, the agricultural water management trends can be classified into distinct categories. Essential and unique innovations under each category are briefly mentioned in the following sections.

5.1.1 Controlled Irrigation

Irrigation is one of the fundamental aspects of AWM. It has driven all the developments in the history of agriculture from crop production, water management, human resource development, and economic challenges. Today the most critical challenge is achieving irrigation efficiency, which means the provision of water and includes applying the right amount at the right time at the right place within the irrigation cycle.

One such approach is Controlled Irrigation (CI). Controlled Irrigation encompasses irrigation scheduling, assessing the optimum crop water requirements and assessment of soil moisture and accordingly quantifying the irrigation water requirement and releasing the same. It has been achieved through combining traditional and new innovative techniques in different parts of the world.

Many of the ICID's recognized technologies under WatSave awards are part of the contemporary Controlled Irrigation practices. Some revolutionary ones include- Mulched drip irrigation, which incorporates surface drip irrigation methods with film-mulching techniques and creates an optimal irrigation schedule for the cotton-growing season. From a broader perspective, the application of water-saving irrigation, soil testing formula, and water fertilizer integration technologies play a significant role in promoting local agricultural production using scientific evaluations. Similarly, the concept of rice-controlled irrigation, which defines the lower limits of root layer soil moisture in different growth periods, is a practical model of CI technology.

Water conservation in a water-hungry crop like rice is necessary considering the scarcity. To overcome such issues, Mandacaru Methodology was implemented in Brazil using furrow-based irrigation that reduced the labour cost and increased productivity and environmental protection.

Innovation and Extension of Sprinkler and Micro-irrigation Technologies have resulted in substantial accumulative water savings worldwide. From a regional perspective, many technologies have been curtailed to suit the geo-climatic conditions and create impact.

For instance, in India, sustainable practices like Direct Seeded Rice and Alternate Wetting and Drying for rice cultivation promoted under ClimaAdapt project made substantial progress at the field, institutional and policy levels in paddy cultivation. In Australia, a system powered by an array of pumps, providing a wide range of crops all year round, culminating in a permanent and efficient irrigation system. All these innovations show that attempts are being made to achieve water use efficiency either by modifying regional techniques, developing new methods, or applying a combination of existing irrigation practices.

5.1.2 Development of Hardware and Software

Efficiency today is not just limited to improved crop yield and water-saving measures but also includes the overall irrigation system's efficiency and water productivity. Today, infrastructure upgrades and technological advancements are increasingly focused on creating replicable, flexible, and sustainable strategies. More specifically, the development of innovative technologies through hardware and software medium for assessing the irrigation water requirements and controlling the release of water has improved the system design to reduce water use.

Presently, smart water management systems augmented with cutting-edge technology can transform irrigation systems worldwide. Harnessing the readily accessible innovations using digital medium, advanced simulation tools for evaluation and optimization of surface irrigation systems offer services for calculating and projecting water availability and requirement, evapotranspiration, irrigation scheduling, modelling droplets from sprinklers to understand the canopy interception better, to name a few. Even though digital management, information collation, and analysis have been a focal point for many innovations in the last decade, the importance of hardware tools creating efficient systems can never be undermined. Innovations such as discharge control valve to regulate pumps for operating at high efficiency, transplanting crops in the bottom of the long trench of V shape to reduce water requirement, intelligent systems consisting of sensors to assess the correct time and amount of water for the crops, and so on are good examples.

These advancements echo the same sentiment that tech-based solutions are in great demand today and will frame the agricultural industry's future. Hardware advancements empowered by digital mechanisms can create seamless and efficient irrigation systems.

5.1.3 Improvements in the Infrastructure

Infrastructural development forms the foundation for irrigation efficiency, equitable water distribution, and a sustainable supply network. Inadequate attention to operation and maintenance issues restricted investments in periodic monitoring, and requisite advancements negatively impact the entire water value chain.

Improvements in the existing infrastructure can include anything and everything from canal lining, system upgrades, infrastructural improvements to arrest leakages and protect evaporation losses, land levelling and water storage facilities, and construction of new irrigation projects. However, it is undebatable that these infrastructural developments are region-specific. Substantial financial and social investments are required from all the stakeholders in developing countries to create new facilities, while developed nations need to focus on advancing and maintaining existing structures.

For instance, the historical South San Joaquin Irrigation District's Pilot Pressure Irrigation Project in Western USA delivered water to farmers through gravity-based canals and pipelines. While the Joaquin district required a new project to meet its water needs, Spain required simple cloth covers to mitigate evaporation losses and save water, ultimately cutting down the annual evaporation losses by 80 to 90% in on-farm reservoirs. Depending on the region, the infrastructural requirement differs. For India, capturing the rainwater as a new water source becomes imperative. An innovative model of roof water harvesting system was implemented in *Mewat* district of *Haryana,* India, where a reservoir was constructed to harvest the runoff water generated from the dyked rice fields. It annually harvested a minimum of 3,00,000 l of rainwater and increased the groundwater availability by 18% when compared to traditional systems.

In a completely different model, the Alberta Irrigation Management Model (AIMM) implemented a rehabilitation of water supply infrastructure aimed at reducing the distribution losses (seepage, evaporation) and improving the on-farm water use efficiency and productivity.

These innovations present different facets of infrastructural development and improvements like rehabilitation, collective management, technological up-gradation, and periodic modifications. From a larger perspective, in the face of ever-changing challenges and over-exploited natural resources, investment in infrastructure remains the key to sustainability. From a governance perspective, timely reforms and public-private associations are also required to promote new infrastructure building and performance evaluations with a stern action plan for the existing structures.

5.1.4 Micro-irrigation

Micro-irrigation has revolutionized agricultural water management completely. Techniques like drip irrigation, sprinkler irrigation, systematic rice intensification, and alternate wetting and drying led to water-saving, increased water productivity, and a higher quality yield. It also led to structured cooperation and coordination among the stakeholders. The most crucial advantage of micro-irrigation is its universal application in diverse geo-climatic zones and various crop groups. ICID ardently supports the development and widespread implementation of these water-saving techniques.

ICID WatSave nominations also witness many micro-irrigation techniques from all over the world. These practices are developed in line with the regional realities. For instance, in Iraq, a concept of Soil Water Retention Technology (SWRT) was developed for converting sandy soils into productive soil while using fewer fertilizers and less supplemental irrigation water.

While in India, subsurface drip irrigation (SSDI) was used in sugarcane cultivation, which increased yield by 10.73% over the conventional Surface Drip Irrigation. This example also shows how micro-irrigation can be used with existing irrigation practices to create a significant impact. One such innovation is the National Program for Improvement of Watercourses (NPIW) in Pakistan. Several on-farm water management (OFWM) mechanisms were implemented to improve the performance of the existing tertiary irrigation system by enhancing conveyance, application, and water use efficiencies. Techniques like drip-sprinkler irrigation, land levelling, and WUA participation were implemented, which created substantial success.

These innovations highlight how micro-irrigation techniques have become all-pervasive as they can be altered and implemented in almost all topographies and agro-climatic zones. Moreover, capacity building and knowledge sharing are some of the ripple effects of micro-irrigation, which accelerates the water sector’s holistic development.

5.1.5 Awareness and Capacity Building

Water management is essentially integrated and systematic handling of the finite resource right from the distribution outlet to the drop penetrating the roots in the field. All the stakeholders play an equally important role in its judicious use and creating sustainable practices. The capacity of every stakeholder, whether an individual or an institution, plays a vital role in the agricultural ecosystem.

Awareness about water conservation, sustainability, water use efficiency empowered with the proper knowledge used at the right time can change the irrigation industry for good. It covers everything from data collection, analysis, ideation, information sharing, and policy formulation to implementing participatory irrigation management on the ground. In this stakeholder value chain, building expertise and a smooth transfer of knowledge hold the potential to create long-term sustainability. There are many international case studies where the focus on participatory capacity building and information dissemination has led to efficiency and water-saving.

In Iran, controlling groundwater level using Participative Management in the Abarkouh region resulted in improved groundwater tables and aquifers such as +27 cm translating to 15 MCM of water. In another case, in 2005, the Nebraska Agricultural Water Management Network (NAWMN) helped participants improve irrigation efficiency by monitoring plant growth stages and development, soil moisture, and crop water use. With participant’s new knowledge, information collation, and the system’s inbuilt decision-making trigger, the system’s efficiency and the producer’s profitability increased. Similarly, in India, focusing on mass awareness and community capacity building, a state-level campaign on water conservation and management called Jalambadi, meaning a ‘school of water knowledge.’ More than 200,000 students from 460 high schools participated in the campaign and took an oath to conserve water. These are only a handful of success stories focused on sharing knowledge and strengthening capacities, leading to tremendous qualitative and quantitative output, water productivity, crop production, joint management, or reduced water conflicts.

5.2 CONCLUSION

The global demand for responsible agricultural production is one of the most significant opportunities for environmental conservation today. But there are many challenges ahead. Presently, one of the biggest agricultural challenges is meeting the growing global demand for food and ensuring increased food production more efficiently grounded in sustainable action.

Irrigation systems have been under pressure to produce more with reduced water supplies. There is an ever-increasing demand for the irrigation sector to be innovative and responsive in a much more holistic manner, rather than the current quasi sectoral approach.

From a structural perspective, governance reforms with clear objectives augmented with technological advancement and participation of multi-stakeholders are required. Global dynamic challenges like political instability through migration and conflict, poverty, population growth, dietary changes, food and nutrition insecurity, energy demands, land degradation, loss of biodiversity, agricultural intensification, gender equity, diversity, and inclusivity are making the situation adverse. New skillsets and multidisciplinary expertise need to be assimilated into the planning and design of new irrigation projects or retrofits to existing schemes.

From an end users' perspective, three important futuristic directions for water conservation are collecting water in the soil, i.e., *improving field capacity and the collectable water volume;* keeping the water inside the soil, i.e., avoiding evapotranspiration with consequence water loss; choosing an appropriate irrigation system to improve water use efficiency and technological solutions *to create a positive impact on the environment and the farm's productivity.*

From a holistic perspective, inter-sectoral water allocations require radical shifts to support continued economic growth. Water use efficiency needs to match the reallocation of 25-40% of water in water-stressed regions, from lower to higher productivity and employment activities. An enabling policy ecosystem promoting technological innovations will play an essential role in agricultural water management. Multi-level institutional development is required from top to bottom, including WUAs, cooperation, departments, the private sector, civil society, and the government. Policy reforms need to be pursued to develop capacities of the sector, and incentives at the bottom should be structured to increase water use productivity through adequate supply-demand management.

6 WAY FORWARD

6.1 INTRODUCTION

This publication, in continuation to the previous one released to celebrate the 60th Foundation Day of ICID and entitled "Water-saving in Agriculture," is to document the outcomes, since then, of the initiatives of ICID towards research, development, and implementation of water-saving in agriculture according to the Vision 2030 and associated roadmap of ICID. It also showcases the continuous progress in meeting the sustainable development goals as adopted by the UN system.

ICID's WATSAVE Awards have been instrumental in bringing out the success stories of irrigation technologies and agricultural water management practices through the contributions made by individuals, research institutions, NGOs, young water sector professionals, and individual farmers or their communities. Other nominated water-saving technologies and practices across the world have also been summarized. The global issues and challenges in the water sector and global perspectives on water savings in different geographies have also been discussed, given the accelerated climate change impacts and the much-required ecological services that the water provides for the broad spectrum of agro-climatic zones.

6.2 CLIMATE CHANGE, WATER AND AGRICULTURE: A ZERO-SUM GAME?

Agriculture is the sector that perhaps will bear the brunt of the visible changes in our living environment. While climate change has been discussed in scientific circles for quite some time, it is now getting mentioned in our daily conversations and media because it is happening around us all the time, and we are directly experiencing it personally, too.

On a positive note – the open field agriculture, the predominant way of food, feed, and fiber production, has always been climate-smart to a very large extent and that too from the very beginning of domestication of plants and animals by human communities some 10-15 thousand years ago as it was the only option for assured survival of all forms of biological life involved in farming. This evolution took place at its own comfortable pace by allowing gradual adjustments here and there by all the components involved, both human and non-human. Presently, it is not the climate but the rate of change that challenges us all. Constantly persistent questions are whether the essential, from the human development point of view, biological lives would be smart enough to quickly adapt to the suddenly changed climate and its associated impacts, and what kind of structural and functional modifications will have to be made in our farming systems to weather this imminent storm. For example, while making certain lands unattractive for cultivation, climate change may open up new areas for food production, and hence there might be a new set of global players in the food market. We are talking about fundamental large-scale shifts in how we live, produce, eat and survive.

At the scientific level, we all know that marginal rise in temperature and concentration of CO_2 in the air are favourable to most crop plants. Still, their impact on pest and soil microbial populations is yet to be thoroughly researched and understood. Other accompanying consequences of climate change are the un-answered ambiguous questions. For example, a gradual temperature rise would most certainly make more water available due to the faster melting of glaciers in the short run. Still, adequate freshwater replenishment would cause concern in the medium to long term due to changing precipitation patterns and erratic behaviours of extreme events such as floods and drought. Desertification of river basins and rising sea level in the coastal parts will certainly add to our difficulties by limiting the supply of land area and freshwater, the two of the three essential physical natural resources for agriculture, besides air.

What we need right now is "mainstreaming climate change" in our design processes for policies, technologies, infrastructure, and development institutions, and of course, in consumer and farmer behaviours. And, it is not only the agriculture sector but all the sectors of the economy will have to respond. Agriculture, responsible for food security and practised in open environments, is at the forefront of this battle line. It is a historic opportunity for this sector to show how other sectors fight climate change or put it more positively and befriend it. The first response should be a unified strategy based on diverse stakeholder consultations, multi-disciplinary approaches, and inter-sectoral collaborations.

We need to be further trained to spend significant time on problem definition before coming up with a solution or a range of available options. So, it is needless to say that the role of our scientific community in understanding climate change impacts on the production of various agricultural commodities is of utmost importance. Our agricultural research institutions need to transform into innovation hubs for developing climate-smart agricultural technologies. Private sector players need to make such technologies more affordable for our smallholders, and government financing schemes need to be more responsive to society's food providers.

The most incredible service we can do for our planet's sustainability is by promoting virtues of efficient, enlightened living and faith in science and leaving behind a wealth of knowledge and wisdom for our future generations so that they do not repeat the history and reinvent the wheel.

Last but not least, there is a vital role of our education and communication agencies in dealing with climate change in agriculture and other aspects of our daily lives. Our curriculum design should factor in climate change, and corresponding adaptation approaches for the preparedness of our future generations. Extension services should communicate climate science to our farming communities to strengthen them to continue to provide overall food security for the human population. It is not just one community's response but the whole society's that will be needed so that we do not end up on the losing side of this zero-sum game.

6.3 THE PREVAILING CONTEXT: WATER VS. ENERGY

Since time immemorial, water, like energy, has enabled the development of civilizations, societies, and communities in all parts of the world. Early human settlements emerged around water availability and flourished by domesticating plants and animals that required an adequate water supply for intensive biological growth. As a result, the human population increased exponentially and, along with this, changed our water consumption behaviour as primarily manifested in our more water-intensive diets, higher sanitation needs, and even water-based recreation. The underlying assumption was always that water is not a limiting factor for growth or development. So much so that we started believing "water is life" and it will always be there in sufficient quantities, leading to our creation of billions of human lives on earth.

However, when the population has reached a level that challenges the adequacy of freshwater availability around us, we are forced to question the validity of our early assumptions of plentiful supplies and more so in the wake of a lack of understanding of future ambiguities posed by the climate change phenomenon. Similar was the case of our worldview and handling of finite coal and petroleum resources. For centuries we used them indiscriminately for development and luxurious living without any inkling that finite is always finite unless we do something about it. Both knowingly and unknowingly, we were also feeding the climate change monster that has come to haunt us now.

Unfortunately, or we can say, fortunately, events of the early 1970's, also known as, Oil-shock, brought us to face complex realities of the finiteness of things around us. We started counting calories by the name of carbon footprint, improving our energy efficiency by both design and choice, exploring and using renewable energy sources such as solar, wind, biomass, hydel, geothermal, and tidal waves. However, we have not reached the point where these new sources have completely replaced coal and petroleum. At least a beginning has been made in our collective consciousness. We are much less alarmed about the global energy situation. What made it all possible was probably our belief in science and its application in finding solutions to the problems of humankind. In many places, solar power generation competes with traditional thermal sources even on economic fronts, besides being environment friendly. In addition to renewable biodiesel, rapid developments in energy storage devices such as batteries are challenging petroleum-based transportation systems worldwide. Hydrogen-powered vehicles are on the verge of becoming new realities. Wind and bioenergy are also being looked upon as new cleaner sources for energy.

Our scientific awakening to face the above energy challenge serves as a powerful guiding light when it comes to the case of the freshwater crunch that we are experiencing and struggling with. We must start counting our water, being more efficient with its use, and more importantly exploring technologies that make it possible to harvest freshwater from oceans, wastewater, ambient humidity, and other unknown sources that may be present around us, just like we did for energy. Water is a complex multidimensional, natural resource that connects people, places, and policies, as depicted in Table 6.1. This complexity is also due to competing demands on the water as it serves many sectors of the economy, cultures, and even religious sentiments of people.

Table 6.1. Water Connects People, Places and Policies/Institutions

People	Decisions	Places	Issues	Policies	Goals
Farmers	Volume, Flow, Time, Quality, Price	Sea	Climate change, Coastal zone management	Irrigated Food, Feed and Fibre Production	Future Security, Resilience
Water User Associations	Equitable availability, Transparent Distribution, Fee, Capacity building	Clouds	Climate change, meteorological issues	Drinking/ Sanitation	Safe and for All
Consumers	Quantity, Quality, Price	Glaciers/ Lakes	Climate change	Energy (Hydro)	Optimum contribution in meeting demand, satisfied beneficiaries
Managers	Meteorological Predictions, Storage Levels, Demand Estimates	Mountains	Agro-forestry, Construction, Tourism, Human interventions	Industry	Adequate supply of desired quality and Safe discharge
Operators	Supply predictions, Distribution plans	Forests	Climate change, Management, Agro forestry uses	Transport	Contribute in minimizing carbon footprint
Designers	Performance of water infrastructure, Future demand and supply, Need assessments	Rivers/ Streams	River basin management, Pollution, Dams, Hydro power potential, Waterways, Recreation, Ecosystem-services	Environment	Adequate e-flows
Markets	Impact of water on food production, Rural demand, Private investment	Dams	Hydro power performance, Displacement and rehabilitation, Safety, Need assessment	Recreation	Optimum use of rivers, lakes, and other recreational structures
Observers	Trends in demand, supply and distribution, Conflicts due to scarcity, Food production, Energy, Transport, Environment, Religion/Culture	Surface and Underground Reservoirs	Capacity, Losses, Maintenance, Need assessment (flood control)	Religion/Culture	Connect people with heritage, Spirituality, Civilizational evolution
		Canals	Maintenance, Sealing, Need assessment		
		Ponds	Costs, Lining, Losses		
		Tanks/Pipes	Costs, Availability, Affordability		
		Fields	Requirement, Productivity, Losses, Water quality, Technology		

Note: Flows to be considered**: Water, Energy, Money, and Information**.

It is not that we are starting from scratch. We have several bright sprouts already visible around us. To begin with, we need to:

(a) further, improve our current understanding and economic uses of the hydrologic cycle by water accounting for various activities using Big Data from satellite observations,

(b) exploit extreme flood events through advanced scientific designs of water storage facilities which can mitigate the variability of freshwater availability and supply throughout a hydrologic cycle,

(c) invest more on making water conservation technologies such as drip and sprinkler irrigation affordable for smallholders, and

(d) research and develop water conversion technologies such as desalinization of brackish and seawater, in-situ wastewater treatment, and water harvesting from ambient humidity.

There might be some more sources of freshwater that have not been explored yet and are waiting for us. Remember, a couple of decades back, harnessing solar energy seemed like the most expensive thing to do in the world. Probably, what the sun did to our awakening, the sea will do the same again.

6.4 POLICY, TECHNOLOGY, FINANCE AND ENTREPRENEURS IN THE IRRIGATION SECTOR

Four main drivers of a sector's growth are similar to a 4-wheeler automobile: enabling policy, innovative technologies, efficient financial models, and entrepreneurship that combines the other three. This analogy helps realize that the automobile will not be stable and un-drivable with a single or more missing wheel(s). The same applies to the irrigation sector.

To incentivize water savings, freshwater governance holds a prominent position in the global policy agenda. Due to population growth and rising incomes, burgeoning water demand is combined with supply-side constraints, such as environmental pollution and climate change, resulting in acute global freshwater scarcity. This is a significant concern because water is a primary input for agriculture, manufacturing, environmental health, human health, power generation, and just about every economic sector and ecosystem.

The prospects for agriculture to respond to the increasing food demand by 2050 are supported historically, but whether this is going to be accomplished is yet to be ascertained given the state of the complementary resources, investment policies, and equity issues surrounding them. And all that has to be done by preserving the ecosystems whose services are essential for all forms of life on earth.

It is a well-known fact that water scarcity is a major constraint for further agricultural development across all geographies, especially in arid and semi-arid regions. Sustainable agricultural development is not feasible without renewable water supplies and appropriate and reliable water control and management. As the human population grows, the demand for water in agriculture will also increase. Knowing this, now is the best time to save water and store what we have to keep our communities functioning smoothly. It is the need of the hour to utilise the water for agriculture in a somewhat different way than the conventional or existing practices. Monitoring the water consumption and other natural resources is central to start tackling the sustainability issues in addition to the adoption of irrigation innovations towards water-saving in agriculture.

Water conservation in farming has become an essential component of the food/feed/fibre production cycle. While it may not be in the farming communities' priority lists because they need as much water as possible in an uncertain environment for future supplies to rear their livestock and crops to survive, it is still essential to implement water-saving strategies to help save water in agriculture. There are not always water-efficient equipment options in agriculture, but it is more about the technique one uses with the equipment that can save water needs for a given crop per unit area. It is possible now to use drone technology, artificial intelligence (AI), and other information and communication technologies to monitor farmlands and make real-time decisions based on reports of where and how much water is required and used.

Water-saving challenges in developing countries include poor infrastructure, need for rehabilitation of old infrastructure, low irrigation efficiencies, negligible reuse and use of poor-quality water for irrigation, and traditional/conventional irrigation methods. Challenges in developed countries also include water quality management, environmental sustainability, use of high-tech irrigation systems, quantification of water value, integrated and holistic approach towards water management, and public awareness on virtues of water-saving.

ICID initiative by way of promoting awards in water-saving in agriculture contributes to addressing some of the national and global challenges and meeting the targets of Sustainable Development Goals (SDGs).

Most of the innovations presented here have demonstrated the contribution towards SDGs, especially by improving water-use efficiencies. Water-saving is as good as creating additional water resources considering increasing water scarcity, increasing food demands and requirements due to increasing population, demand for better quality foods because of rising economic levels. All these factors prompt that water-saving is not only desirable but also essential for our long-term survival.

The innovative research, irrigation infrastructure, and management techniques follow the ICID vision 2030 towards water-saving goals and promote member countries for their contribution in meeting the SDG. The global issues and challenges such as population growth, urbanization, climate change, and competition for water resources are expected to increase, impacting agriculture. The promotion of water-saving techniques and practices will help in addressing these challenges.

The development of one type of innovation often helps promote further research in continuation to the previous work. This will enable the enhancement of technical and management capacities. It could be seen that most of the innovations are not new. Most of these have been talked about in theory and various forums. Still, these innovations serve as success stories of irrigation technology and techniques in terms of ease of implementation and quantification of realizable water-saving.

The concept of groundwater recharge has been demonstrated as additional infrastructure for water conservation, with the growing difficulties in creating surface water storage due to land acquisition, environmental impacts, and capital investment.

Such innovations also promote the role of industries in developing hardware, thus adding to employment opportunities and improving a region's economy. These innovations help develop international cooperation in terms of technology transfer international trade and open other avenues of cooperation.

It has also been demonstrated that new water resource development policies and water-saving are required, and so does a strong will for implementation and monitoring framework.

These innovations illustrate the success of implementing better management practices. The number of nominated innovations are related to water application techniques and farmland preparation for increased crop yield with less water.

Farmers perceive that the income from the product is not commensurate with the efforts, labour, inputs costs in terms of seeds, fertilisers, and pesticides. Most water application and management techniques have resulted in a substantial increase in farm produce with less labour and less cost of inputs, making the farmers economically prosperous.

Innovative irrigation practices can enhance water use efficiency for economic advantage for farmers while also reducing environmental impacts. Water-efficient methods and better irrigation scheduling could also combine water and nutrient management, thus minimising agrochemical runoff and leaching problems. To help fulfill this potential, experts have developed various models of water efficiency and environmental benefits. Yet these models are scantly used for irrigation scheduling in real-life situations.

For any type of water conservation program, it is important to understand what happens to the applied irrigation water, i.e., where does all the water ultimately go? If one understands what happens to all components of the diverted water, then one can assess what benefits result from water conservation.

The applied irrigation water can be categorized as:

(a) Water consumed by the crop within the area for beneficial purposes.

(b) Water consumed within the area under consideration but not beneficially.

(c) Water that leaves the boundaries of the area under consideration but is recovered and reused.

(d) Water that leaves the boundaries of the area under consideration but is either not recoverable or not reusable.

(e) Water that is in storage within the boundaries.

This differentiation can help identify improvements that would result in true water conservation.

The following five points expand on and explain the five categories above:

(a) The water is used to produce a crop and is consumed by transpiration from plant leaves or the soil beneath or between plants. Reducing this water consumption generally reduces yields of marketable produce—the water evaporation from soil averages 10 to 20% of total consumption (ET). Buried drip irrigation claims a benefit here since the soil surface is sometimes not wetted, and thus the evaporation component can be reduced with only a slight increase in transpiration. However, claims of large savings in water consumption are physically unreasonable since buried drip systems can generally only reduce evaporation by about one-half and consequently can create savings of only 5 to 10% of total consumptions and likely only 2 to 5% of total water diverted. This results in real water conservation, particularly in arid environments since ET is substantially reduced. However, fallow land can have negative environmental consequences if not done properly (soil salinization, and wind erosion). Genetic improvements to produce more crops with less water are possible in some cases, but usually, more crops with the same water (or the same yield on less acreage and thus less water).

(b) This includes water lost through evaporation from soil away from crops or open water surfaces and evapotranspiration from weeds, trees, phreatophytes, and other vegetation in the field. Many of these losses are difficult and costly to avoid, but there are opportunities in some cases. Some of the lost water may have environmental benefits by supporting trees, windbreaks, incidental wetlands, and so on that are attractive to wildlife.

(c) Water that is recovered and reused is not a target for water conservation. The water is already being reused, so reducing this from entering the irrigation system often has no real benefit. There are exceptions, for example, where it reduces cost or improves the quality of this water or where allowing the water in a reach of a stream has an environmental benefit. In some cases, the delay in unconsumed irrigation water returning to the stream has an environmental benefit by buffering streamflow during droughts or winter.

(d) This water is the primary concern for water conservation efforts. Here water is unrecoverable because of large depths to groundwater or is not re-useable because of salinization or entry into a saline body. A reduction in water applied for irrigation means that it can be used for other purposes. It is water saved.

(e) Irrigation water that is in storage within the area of consideration is not considered as used. Its ultimate fate is yet to be determined. The delay caused by storage may have positive or negative economic and hydrologic impacts

The innovations covered in this publication on the use of water-saving techniques, technologies, and practices across the globe have sufficiently demonstrated the need for more and more use and spread of these success stories to meet the future water challenges. ICID, by way of the promotion of Watsave Awards, has promoted and spread a message across the globe. At times, ICID assists in developing national capacities and programs of the members through partnerships with other like-minded international partners, multi-national corporations, and NGOs. We will realize that it is still a long way to go.

Some of the most successful business models entail the participation of the private sector, adequate government support, and the active involvement of the community. Each value chain actor plays a specific role in adopting innovative irrigation beneficially at the farm level. For example, through its policies, the government may provide capital support to the farmers through subsidies. In contrast, the private sector may actively conduct capacity-building programmes and provide after-sale technical support to the farmers.

Business models involving the coupling of innovative irrigation systems to grow commercial vegetables and crops locally have yielded highly positive results in the arid and semi-arid regions globally. Contract farming is yet another potential business model where the farmers receive support from the private sector for the entire production value chain. Another model is the private sector working with progressive farmers for local technical support. In almost all the success stories, the private sector plays the catalytic role in manufacturing irrigation equipment and setting up local distribution and after-sale services. The private sector needs to work more closely with the farmers, local extension, and irrigation officials to accelerate the capacity building of farmers for the adoption of innovative irrigation systems.

6.5 SUMMING UP

Finally, the innovations listed in this publication have collectively shown the concept of “more crop per drop.” One technical issue that should draw our attention is the term “Irrigation Efficiency”, which is interpreted very subjectively and mainly through our resource deployment point of view. Science generally defines efficiency as the ratio of output and input – two quantities having the same measure of units. Accordingly, “irrigation efficiency” would be a ratio of water output (essential for achieving a particular crop’s growth potential) and water input (the irrigation water released at various tempo-spatial levels. Most people think of “irrigation efficiency” as “more crop per drop,” scientifically the measure of crop-water productivity is expressed as kilograms of crop harvested divided by litres of water used to grow that crop mass. However, in the context of differing agro-climatic environments, it is not possible to arrive at unique values of this magic number even for the same crop variety. Much has been discussed and written about this confusion, but it should be resolved based on science to have a common understanding among the irrigation stakeholders.

Water productivity in agriculture, a standard measure of crop water performance, is essentially a function of the technology used in water application. Other factors may include the crop and soil type, water management practices, and precipitation levels. Flood irrigation has been a traditional water application method in most situations globally, even in water-scarce conditions, and it has both its pluses and minuses. However, as the water demand grows in the other sectors of the economy, agricultural water use attracts the first attention of policymakers and water resources managers for potential savings. The general expectation or prescription is that agricultural water use needs drastic improvements to share water more justly among the various demands.

Irrigation and water resources engineers have been tackling this issue ever since the more significant freshwater diversion began growing to other sectors such as industry, tourism, and domestic supplies. Disregarding the ecological and environmental benefits of flood irrigation, the current thinking in the sector tilts towards improving crop water productivity, meaning more production with less water application as a way forward. Precision irrigation technologies that match the crop water requirement with the available supply are an area that has received significant research interest. As a result, many innovations are now becoming commercially viable. The principle behind precision irrigation is quite simply that the crop water requirement needs to be measured as accurately as possible using state-of-the-art technology. This requirement should be met as exactly as physically possible in any given spatial-temporal setting. In this context, it is generally assumed that some other agency or mechanism will take care of the environmental flows of water in the absence of any holistic ecology-based natural resources policy system.

We have witnessed the constant technological developments in the fields of satellite or sensor-based water measurements, efficient water transport and delivery systems, and scientific management regimes that make precision irrigation possible. Unfortunately, these expensive options are mostly confined to the developed world. In the developing world, no doubt such technologies are becoming available, but they still are beyond the reach of most smallholders. That is why we need a continuously evolving innovation ecosystem, and that is what ICID Watsave Awards precisely endeavour to promote.

This publication is brought out as part of the ICID's 70th Anniversary Celebration. Since 1998, the WatSave Awards have been presented each year to recognize globally outstanding contributions to Water Conservation or Water-Saving in Agriculture. The first edition of this publication was released in 2008 includes case studies from Australia, Brazil, China, India, Egypt, Korea, Pakistan, South Africa, Spain, Turkmenistan, and the USA. This edition includes case studies received from a total of 105 nominations in different categories of the "WatSave Award" (2008-2020).

COMMISSION INTERNATIONALE DES IRRIGATIONS ET DU DRAINAGE (CIID)

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