By 2050 the world’s population could exceed 9 billion, a 50% increase compared to 2000. Food production will therefore have to increase globally by 70%, perhaps by 100% in developing countries. Producing more food will require more water, yet water shortages and water scarcity are already a problem in many parts of the world. Water use has been growing globally at more than twice the rate of population increase in the last century and an increasing number of regions are reaching the limit at which reliable water services can be delivered. By 2020, water use is expected to increase by 40%, and 17% more water will be required for food production to meet the needs of the growing population.

With contributions from international experts, Water Management for Global Food Security demonstrates how water supplies and food security issues vary widely between and within countries, and what can be done to boost food production, so as to reduce poverty and malnutrition among the world’s most vulnerable people.

ABOUT THE EDITOR

Dr. Chandra A. Madramootoo is Dean of the Faculty of Agricultural and Environmental Sciences, Associate Vice-Principal of McGill University, and a James McGill Professor in the Department of Biosystems Engineering. He was the driving force behind the creation of the McGill Institute for Global Food Security, as well as McGill’s brace Centre for Water Resources Management. Dr. Madramootoo’s areas of expertise include irrigation, drainage, water quality, agricultural research, and international agriculture development. He is currently President, International Commission on Irrigation and Drainage (ICID).

Water Management for Global Food Security
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Water Management for Global Food Security

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This publication has emanated from the work of the McGill Institute for Global Food Security and the annual McGill Conferences on Global Food Security. The Institute was established in 2010, and the first Conference on Global Food Security was held in September 2008, in the midst of socio-economic turmoil in many developing countries due to record high food prices. World leaders and heads of international development agencies at the time became pre-occupied with the topic of global food security. It was apparent that the First UN Millennium Development Goal to halve the number of people suffering from hunger was not going to be achieved.

Regrettably, the situation of global food insecurity has worsened since 2008, with some one billion people still suffering from hunger and malnutrition. The 2009 World Summit on Food Security called on governments, the donor community and private sector to increase investments in agriculture and boost agricultural productivity. The Summit noted that a healthy agricultural sector is essential to overcoming poverty and hunger. This is particularly noteworthy given that agriculture contributes to the livelihoods of 70% of the world’s poor. A vibrant agricultural sector is an essential pathway to poverty alleviation and higher standard of living of the world’s most vulnerable people.

A recurring theme of the three McGill Conferences on Global Food Security is the impact of water on food security. In many countries, over 70% of all freshwater withdrawals are used for food production. The fear is that with rising water scarcity and increased competition for water by other economic sectors, there will be insufficient water to meet growing food demands of the world’s population in the future.

The critical importance of managing water for food security is therefore emphasized in this book. We are fortunate to have inputs from some of the world’s leading experts in
water. These experts have not only made an impact at the global scale, but they have also been leaders in water management in their respective countries or regions. Many have been speakers at the three McGill conferences and we are grateful for their contributions.

Special gratitude is extended to Helen Fyles who has worked tirelessly to edit the various chapters and bring the publication to fruition.

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Dr. Nabarro served as Executive Director at WHO working on the Commission on Macroeconomics and Health, Health Systems Assessments and creation of the Global Fund to fight AIDS, Tuberculosis and Malaria. In 2003, Dr. Nabarro became head of Health Action in Crises (WHO), coordinating worldwide support for health aspects of crises preparedness, response and recovery. In 2005 he was appointed Senior UN System Coordinator for Avian and Pandemic Influenza and UN Assistant Secretary-General. In 2009 he became Coordinator of the UN system’s High Level Task Force on the Food Security Crisis. In 2009, Ban Ki-Moon, UN Secretary General, appointed him as his Special Representative for Food Security and Nutrition.

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Prof. Schultz’s career includes more than 35 years of research, advising and project implementation in land and water development, drainage, irrigation, flood management and environmental engineering. He has a part time appointment at the UNESCO-IHE Institute for Water Education, responsible for education and research in land and water development. Until 2009 he was top advisor in Rijkswaterstaat, Civil Engineering Division responsible for environmental impact studies on major hydraulic works and implementation of large scale environmental engineering projects. From 1999 to 2002 he was President of the International Commission on Irrigation and Drainage (ICID).
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At no time in our history has the linkage between water, food, energy, climate, human development and economic security been as strong and critical as we are witnessing today. These are enormous threats to global development. Despite the attention of world leaders, the forecast for the immediate future is rather bleak for hundreds of millions living in water, food and resource scarce regions of Africa, Asia and Latin America.

It is estimated that by 2050 the world’s population will reach nine billion, and much of this population increase will occur in developing countries. Most of this growth will take place in urban areas, as urban populations increase from a current estimate of 3.5 billion (50% of total population) to 6.3 billion (69%) by 2050 (UN, 2010). Average income levels, particularly in emerging economies, are also increasing, implying changes in dietary habits to higher value foods. The United Nations Food and Agriculture Organization (FAO) estimates that to feed this population increase, food production must increase globally by 70%, and by 100% in developing countries (Bruinsma, 2009).

Against this backdrop of demand for higher food production in the future, is the fact that over one billion people are currently malnourished. The proportion of people who suffer from hunger in the total population is highest in sub-Saharan Africa, where one in three people is chronically hungry. Two-thirds of the world’s undernourished live in seven countries: Bangladesh, China, Democratic Republic of Congo, Ethiopia, India, Indonesia, and Pakistan.

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* Dean, Faculty of Agricultural Environmental Sciences, McGill University; President, International Commission on Irrigation and Drainage (ICID)
By virtue of their size, China and India combined account for 42% of the chronically hungry people in the developing world.

The FAO estimates that about 1.5 billion hectares of the globe's land surface is currently used for crop production. While it might be possible to cultivate another 2.7 billion hectares, the view is generally held that additional cultivation will come with enormous costs and destruction of the environment, biodiversity, wildlife, wetlands, watersheds, and sensitive and fragile ecological habitats.

Water management is a critical input to food production. In the wet humid regions and low lying coastal regions, excess water must be removed by drainage systems to achieve crop production. These regions also suffer to some extent from dry periods each year and supplemental irrigation is required. In the drier arid and semi-arid regions, irrigation is vital for crop and livestock production and food security.

Agriculture accounts for 70% of global fresh water withdrawals worldwide and more than 90% of its consumptive use. Agriculture is increasingly in competition with other economic sectors, municipalities, and the environment for diminishing water supplies. As noted in Figure 1, extensive parts of the developing world are major agricultural water users. With

Figure 1. Freshwater withdrawals in the world (Rekacewicz, 2002)
rising water demand from non-agricultural sectors and the uncertainties in water supply brought about by climate change, the agricultural sector in many areas will likely get less water in the future (Bakkes, 2009). Together, the increasing demand for water for food production and the limits of the availability of water resources suggest that agriculture must produce more food with less water (Cai and Sharma, 2010).

Water scarcity is already a problem in many parts of the world (Figure 2). Water use has been growing globally at more than twice the rate of population increase in the last century, and an increasing number of regions are reaching the limit at which reliable water services can be delivered. Approximately 1.2 billion people live in river basins with absolute water scarcity, where water resource development has exceeded sustainable limits, and a further 1.6 billion suffer from inadequate access to water because of a lack of infrastructure or the human and financial capital to tap the available resources (Molden et al., 2007). Contamination of water supplies by agricultural, municipal and industrial effluents further limits water consumption. Climate change is also projected to have a significant impact on water availability. It is generally agreed that climate variability and the frequency of extreme weather events will increase even in the near term in all regions. Reserves of water in mountain glaciers are declining, thus affecting river flows and water availability during growing seasons (IPCC, 2007). By 2020, water use is expected to increase by 40 %, and 17 % more water will be required for food production to meet population needs (Palaniappan and Gleick, 2009).

**Figure 2.** Projected water scarcity in the world (Comprehensive Assessment of Water Management in Agriculture, 2007)
IRRIGATION DEVELOPMENT AND ITS CONTRIBUTION TO WORLD FOOD SUPPLIES

Of the 1.5 billion hectares of cultivated land, some 300 million hectares are irrigated, with over 70% being in Asia. Although irrigation has been practised for millennia in various parts of the world, it was the advent of the Green Revolution in the late 1960s to early 1970s which really spurred modern day irrigation in the developing world. Storage for irrigation water supplies and construction of the water delivery network heralded the expansion of rice, wheat, and maize production in Asia, Africa, and parts of Latin America. A point particularly worthy of note is that this irrigated land (20% of the world’s cropland) provides 40% of the world’s food (UNCSD, 1997). Irrigation stabilizes crop production, improves crop quality, allows for crop diversification including the introduction of new crops that are not generally viable under dryland farming and, of particular importance, helps to reduce rural poverty (World Bank, 2006). Unfortunately, we have witnessed a decline in irrigation investments over the past 25 years, and this is one reason given for current global food insecurity.

The irrigation sector has also suffered from a variety of problems, including poor irrigation practices, soil salinization and waterlogging, weak institutional management, system inefficiencies, failure to recover operational costs, failure to innovate and integrate new technologies into the irrigation network, lack of adequate operation and maintenance and rehabilitation of infrastructure, and water quality impairment. Farmer confidence in centrally operated irrigation systems may have also declined where water was not equitably and uniformly distributed. This led to farmers manipulating and disrupting the system, withdrawing water improperly and illegally, and the installation of individual tubewells to supplement canal water supplies. The latter has led to groundwater exploitation and lowering of water tables in many parts of the world.

There is no doubt that the above factors led to disenchantment, particularly of governments and donors, in the performance of the public irrigation sector. The return on public investments and loans on massive water infrastructure projects was being seriously questioned. This is another reason for the downturn in publicly funded irrigation projects. Nonetheless, the sector was quick to recognize the problems and a series of technical, institutional and financial reforms were undertaken in many countries.

IMPROVING IRRIGATION PERFORMANCE TO ACHIEVE FOOD SECURITY

Over the past few years, there have been several initiatives aimed at improving the performance of the irrigation sector. These include:

- Introduction of water savings technologies including drip irrigation, where appropriate;
- Improved on farm water management systems, including land levelling, better hydraulic designs of basins, borders, and irrigation furrows;
- Use of pressurized and low energy irrigation technologies, where possible;
INTRODUCTION

- Lining of irrigation canals to reduce seepage;
- Installation of subsurface drainage to control waterlogging and salinity;
- Automated water control structures on canals and outlets;
- Moving from a water supply controlled network to a more demand driven network based on crop water requirements;
- Implementation of water pricing and cost recovery;
- Reform of the irrigation services including establishment of water users associations;
- Incorporation of environmental safeguards into the design and operation of irrigation systems;
- Training of farmers, irrigators, system operators and water users, and support for participatory irrigation management.

Many countries lag behind in implementing many of the measures listed above and their adoption should be a priority. Studies by Rosegrant et al., (2002) and the Comprehensive Assessment of Water Management in Agriculture (2007) give rise to optimism. The Rosegrant et al. (2002) work, based on scenario modelling using the IMPACT-WATER model, indicates that with improved water policies, ramped up investments in water and irrigation, technology innovation in crops and water, and attention to rainfed cereal production, growth in food production can be attained and at the same time demands for piped water and environmental flows can be achieved. The Comprehensive Assessment of Water Management in Agriculture (2007) focuses on increasing the physical productivity of water. This means reducing water losses, and reuse of irrigation return flows, drainage water and wastewater for crop production. Moving water to higher productivity benefits is another suggestion. However, these all require an appropriate policy and institutional environment.

MOVING FORWARD

While there have been significant advances in irrigation system design and operation in several countries in the recent past, much remains to be done in light of growing global food demands and concerns about water scarcity. Water resource use is a complex issue within the food security debate, and it cannot be divorced from the inter-related factors of markets, trade, energy, food prices, institutional frameworks, and the overall agricultural development system.

Water management is only one of many inputs to achieve food security. Others include agrochemicals, soil and land management, germplasm, crop processing and storage, on and off-farm infrastructure, education, extension services, and credit. There are wide crop yield gaps (the difference between agro-ecologically attainable and actual yields), and these can be narrowed through the above technological interventions.

Understanding the unique political, socio-economic, cultural, and biophysical (including soil and water) context of a particular region is a prerequisite for attaining food security.
In an analysis of 10 river basins, many with high levels of poverty, Fisher and Cook (2010) pointed to the unique set of characteristics and underlying problems in each basin which must be addressed if basin food security is to be increased. For example, in the intensively developed Yellow River Basin (Ringler et al. 2010), over one-half the agricultural area is irrigated, and essentially all water is allocated. Per capita water availability is 430 m$^3$ and well below the 1000 m$^3$ threshold for chronic water scarcity (Falkenmark and Widstrand, 1992). The poverty level averages 30%, and rises to 50% in the upstream area. This basin also has the world’s highest sediment loads, large flooding events and high levels of water degradation in some areas. However in 2000, the basin produced 14% of the Chinese grain harvest, and 14% of the country’s GDP using only 2% of national water resources. Despite water scarcity and other biophysical limitations, there are high levels of production and high water productivity (amount of crop produced per cubic meter of water) in many parts of the basin. In contrast, in the under-developed Niger River Basin in West Africa, only 20% of the arable land is cultivated, and of that only 15% is irrigated (Ogilvie et al., 2010). Poverty levels are high throughout the basin (as high as 70% in Burkina Faso and Guinea), and rainfed water productivity is around 0.1 kg/m$^3$, around 10 times lower than in temperate regions. Although both basins have significant numbers of people who are food insecure, developmental solutions to raise food security would be completely different in these two locations.

In the tropical drylands, extreme rainfall variability, recurrent and unpredictable droughts, flooding, warm temperatures and a fragile natural resource base with inherent low fertility soils are a challenge to farmers struggling to produce food in regions where more than half the population is undernourished. Rainwater harvesting and crop genetic improvement through the breeding of drought and salt tolerant lines are key necessities.

As noted by Rosegrant et al. (2002), some 50% of the world’s cereals are produced on rainfed lands. Therefore the contribution of rainfed agriculture cannot be neglected. Drought tolerant crop varieties, biotechnology, tillage and water conservation practices, soil moisture management, and investment in rainfall harvesting systems must not be ignored.

Precision irrigation, deficit irrigation (Fereres and Soriano, 2007), alternate wet and dry irrigation, alternate furrow irrigation (Webber and Madramootoo, 2008), and measuring and managing soil moisture to meet crop evaporative demands are some of the techniques which can be used to save water. If innovations in irrigation and water conservation are to succeed, better water accounting models are required (Ward and Pulido-Velazquez, 2008), particularly at the basin scale. Water rights, water markets, water transfers, and water accounting need to be defined not just in terms of water applied, but also for water depleted. This will guard against false expectations that water is actually being saved, and hence more area can be irrigated, simply by adopting water conservation measures.

There is cause for concern about the current state of groundwater exploitation for irrigation. Nearly 38% of the total irrigated land area is equipped for groundwater irrigation. There has been a significant rise in the use of shallow groundwater for crop production in many parts of Asia, Africa, Mexico, and the United States, to name a few. One of the most
alarming examples of groundwater over-exploitation occurs in the Ogallala aquifer of the south-western United States. This 450,600 square kilometre aquifer covers parts of 8 states, and about 12% of the aquifer area is irrigated by center-pivots. There has been a 9% decline in aquifer storage since its development. Data for other aquifers around the world is difficult to obtain, since there is little monitoring of groundwater levels or abstractions. Wada et al. (2010) have modelled groundwater depletion globally, and have stated that groundwater abstraction has gone from about 312 cubic kilometres per annum to over 734 cubic kilometres per annum, in the past 40 years. There is clearly a need for a system of groundwater monitoring, permitting and pricing, as well as a better assessment of the resource, to avoid its unsustainable exploitation.

There will be on-going debates about the use of land and water to produce biofuels. Are current biofuel policies appropriate, given the large amounts of land and water that are being diverted from food production? The question of land acquisitions, particularly in Africa, is also controversial, since rights to water and land are often inseparable. These two issues, biofuels and land acquisitions, will demand much more analysis and scrutiny in the context of water for food security.

It is clear that the 500 million or so small landholders, who have limited or no access to water, credit, input supplies, and who lack appropriate land tenure, are critical to food and nutritional security, particularly at the local village and community levels. What is not clear, despite the best efforts of microfinance schemes and extension services, is how these small holders will secure the property rights to advance their economic well being. Of further concern is whether sufficient attention is being given to the education and training of female irrigators and farmers on techniques of irrigation, water conservation and crop production. There is a call for stronger female participation and voice in water user associations, for example.

In going forward, the challenge is to position water and the irrigation sector as a driver of economic growth in rural areas, and a contributor to peace and prosperity in shared river basins. Water based economic development which has the twin objectives of achieving food and nutrition security, and improving the socio-economic status of rural agrarian communities, is a goal worthy of much stronger pursuit. Clearly a combination of public and private investments is crucial for success. A much different set of highly trained human skills than currently prevails will be required. The World Economic Forum (2009) pointed out that apart from new technologies; there must be new markets and new financing ideas to meet the challenges of global food security. The public and private sectors will have to develop new partnership models in order to secure the financing needed for water and food security. Moreover, a fairer international trading system is critical for transitioning to improved water and food productivity in poor rural areas.
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INTRODUCTION


2. GLOBAL RESPONSE TO FOOD SECURITY

David Nabarro*

ABSTRACT

Universal access to sufficient and nutritious food in a sustainable environment is a global challenge and is a priority for Ban Ki Moon, the United Nations Secretary General, and also for international organizations including the FAO, World Food Programme, International Fund for Agriculture and Development, World Bank, UN Development Programme, regional banks, the WTO and OCHA. In 2008 when food prices rose sharply, the UN Secretary General established a High Level Task Force on the food security crisis that focuses on the immediate needs of food insecure populations as well as the long term structural challenges of ensuring food security for all. The focus of this chapter is on the ways in which different parts of the international system work together in pursuit of the two tracks with a particular focus on the world’s most vulnerable populations. Efforts during the past three years have focused on scientific challenges, financial investment, technical support and governance.

HIGH LEVEL TASK FORCE

Universal access to sufficient and nutritious food in a sustainable environment is one of our main global challenges. It is a priority for Ban Ki Moon, the United Nations Secretary General, and also for all agencies that I have identified. The international initiatives discussed here are part of a broader inter-governmental and international movement that is pursuing a comprehensive and long-term approach to food security. It has a particular focus on the

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sustainable access to food and essential nutrients for the billion people in our world who suffer from poverty and hunger.

In 2008 when food prices escalated to a very high level, the UN Secretary General established a High Level Task Force on the food security crisis, made up of UN agencies, funds and programs as well as the international financial institutions, the Organization for Economic Cooperation and Development and the World Trade Organization. This task force pursues a comprehensive twin-track approach to food and nutrition security that focuses on the immediate needs of food insecure populations as well as the long term structural challenges of ensuring food security for all.

The approach is spelled out in our Comprehensive Framework for Action which was completed by the HLTF within its first three months. It has now been updated following extensive discussions with stakeholders.

Momentum for real improvements in hunger and poverty reduction that have been gathering over the last few years. We started from a very difficult place. Levels of global hunger had been increasing since 2003 due to high food prices and the economic crisis. A billion people were identified as chronically hungry in 2009: the number has slightly reduced to 925 million now. But still it is far too high and reductions way below what is necessary for the realization of the first Millennium Development Goal. Additionally the trends in under-nutrition are not good, with extreme variations region by region.

Government investments in agriculture and food had declined over the last three decades but changes are in the wind. We have seen a reverse in the negative trends in agriculture investment. We have seen governments giving increasing priority to hunger reduction and nutrition as priority development outcomes. This point was made very strongly in the summit on the Millennium Development Goals that took place in New York at the end of September. The investment approach starts from people themselves and their basic rights – including the right to food. It gives emphasis to their livelihoods as well as their lives, focusing on the interests of women at all times, with productive safety nets and protection in case they are unable to fend for themselves, resilience in the face of climate change and unexpected shortages and special attention to the needs of smallholder farmers and marginalized people wherever they live. Development efforts increasingly prioritize food, water and land security, are sensitive to the drivers of under-nutrition and include a range of specific, cost-effective and proven interventions that make a real difference to newborn, infant and child nutrition thus increasing their learning and productive potential when older. These nutrition efforts are increasingly being scaled-up and made available to all.

At the same time, communities and countries affected by prolonged food insecurity are also at risk of chronic under-nutrition and need more than repeated bursts of humanitarian aid. Long-term investments that strengthen their livelihoods, empower their institutions and encourage regional solidarity are key, and these are not easy to mobilize given these nations’ political and institutional weaknesses.
Concerted efforts from the international community, particularly from ministers or those responsible for food security, is needed to sustain these recent positive trends for increases in investment and to respond adequately to protracted crises and also to the impact of climate change.

**ACTIONS TO ADDRESS FOOD SECURITY**

Figure 1 identifies how the actions spelt out in the Comprehensive Framework for Action address all dimensions of food security: availability of food, stability of food supplies, access to essential nutrients and utilization of nutrients so that they will lead to long term well-being. We see in addition that capabilities have to be developed so that they can respond to these four dimensions of food insecurity to all levels: ensuring that all can access and consume adequate nutrients at all times from conception through to old age is particularly challenging given the underlying inequities that are found in countries at all stages of development. This is why Ban Ki-Moon, in a message last week, stressed the importance of the Right to Food as a basis for all actions on food and nutrition security.

The focus of my talk this afternoon is on the ways in which different parts of the international system work together in pursuit of the two tracks - immediate action in response to those who are most urgently in need of help and efforts to ensure longer-term food security – and resilience in the face of shocks – with a particular focus on the world’s most vulnerable populations (Figure 2). Efforts during the past three years have focused on:

a) ensuring that the best science is available, through research and analysis that reflects the interests of the world’s poorest people [and, to this end, governments have recently established an independent High Level Panel of Experts to tackle the most difficult scientific challenges, and have reformed the Consultative Group on International Agricultural Research – or CGIAR – system],

b) on increasing and better coordinating financial investment by development partners (loans and grants) and by the private sector,

c) aligning and ensuring coherence of technical support through international organizations (and that is what we have been doing within the High Level Task Force) and

d) improving governance so that it reflects the interests of all countries and their peoples (through the revitalized Committee on Food Security).

During recent months we have witnessed new opportunities for the increased participation of groups focusing on the enjoyment, by all people, of the Right to Food, and there is increasing scope for their activism to be expressed within these different parts of the international system. Figure 3 shows some of the different initiatives that have been taken forward to address different aspects of food and nutrition security. This is what has been referred to as the Global Partnership on Agriculture, Food Security and Nutrition.
Figure 1. The dimensions of food security

New initiatives address all dimensions of food security

- Investments into agriculture
  - Short-term boosts
  - Longer-term support for sustainable agriculture
- Enhancement of resilience of rural communities
- Improvement of smallholder productivity
- Adjustment of trade and tax policies
- Improvement of international food markets

- Interventions on prices, stocks and movements
- Investment into climate change adaptation and mitigation
- Management of macro-economic implications
- Development of international bio-fuel consensus

Availability
Production systems and food markets

Access
Physical access and purchasing power

Reduced volatility over seasons and years

Consumption of adequate nutrient mix

Stability
Utilization

In addition institutions and capacities need to be strengthened at all levels

Figure 2. Focus for action on food security
In Africa, the Comprehensive Africa Agriculture Development Programme brings together different countries under the unified umbrella of the African Union to have a mechanism for scaling up investments in smallholder agriculture with peer reviewed compacts at the national level (Figure 3). Twenty compacts have been put in place since 2008 and are leading to country-led comprehensive food security investment plans being developed in conjunction with the multilateral agencies and the donors. These are being taken forward by all working together both at regional and sub-regional (e.g. Economic Community of West African States, ECOWAS) level.

At the global level, the November 2009 World Food Summit called for a reinvigorated Committee on Food Security as an international governance mechanism for food security. It is a manifestation of the GPAFSN at the inter-governmental level. The reformed CFS has just met in Rome.

The L’Aquila Food Security Initiative (AFSI), announced at the July 2009 G8 summit by 26 nations and 14 international organizations, is an effort by nations of the world to invest increased financial resources in food and nutrition security at national levels. These development partners want to show that they are able to provide backing through pledging and then providing resources (so far $22 billion have been pledged). Canada has chaired the AFSI group this year and has strongly emphasized the need for (a) careful tracking of funds, (b) alignment of donor assistance around country plans, and (c) accounting for funds spent. There has been significant progress in Rwanda, Bangladesh, ECOWAS countries and Haiti.

Figure 3. The Global Partnership on Agriculture, Food Security and Nutrition
For the last few years countries (especially in Africa) have been encouraged to develop peer reviewed and comprehensive food security investment strategies and have come to believe that this approach will enable them to access the resources they need to support their national investment strategies: this is why a system of pooled donor funding is important to enable countries that need funds to get them even if they are not preferred recipients of bilateral donor assistance. In September 2009, the G20, meeting in Pittsburgh, called for a Global Agriculture and Food Security Programme (managed by the World Bank) to provide grants to well-prepared national food security investment plans. Canada – along with the US, Spain, Korea and the Gates Foundation - has been a key contributor to this funding mechanism. It really is an excellent development.

GAFSP provides donors with a system for supporting food security programmes which has several desirable features for beneficiary nations – it is predictable, transparent, with independent assessment of proposal quality and with a strong focus on results. GAFSP backs country investment plans that reflect the five l’Aquila principles: there are no conditions for the kinds of proposals that are eligible for GAFSP support. GAFSP builds on existing well-functioning support systems and is not a new fund – the monies are routed through existing “supervising entities” - but the country is able to choose which supervising entity it wants to see involved in project implementation and to stipulate performance indicators for the work of that supervising entity. Civil society and farmers’ organizations from developing as well as OECD countries are an integral and important part of the steering committee for GAFSP and there is a requirement that proposals are developed with their full involvement. GAFSP incorporates three windows – offering countries a chance to access support for financial investment via the public sector or private sector, and to receive support for the building of in country capabilities for food security. GAFSP is in sore need of additional resources to ensure that there is enough available for the second major distribution at the beginning of November.

**Figure 4. The Rome Principles**

**All initiatives adhere to Rome principals**

1. Support for country-led plans for Food Security
2. Pursuing a comprehensive approach (all dimension of food security)
3. Coordinated action at local, national, sub-regional, regional and Global levels
4. Multilateral action with a strong role for the multilateral action
5. Increased national and international investments with...
6. ...transparent tracking and mapping of progress
All these initiatives adhere to the Rome principles (agreed at last year’s World Food Summit) for support to country-led plans with comprehensive approaches coordinated at all levels with strong multilateral action and increased national and international investments with transparent tracking and monitoring of progress in order to demonstrate results (Figure 4).

CONCLUSION

It is now time to make food security a reality and realize MDG1 (Figure 5). This means keeping people – and their food and nutritional security – at the centre of all that we do. This means maintaining the focus on smallholder agriculture – investing in small-scale farmers, agribusinesses, processors and markets. It means building the capacity of farmers’ organizations and associations so that they can be fully involved in policymaking and practice – working for poor people means working with them.

Because most food production, processing, marketing and trading is a private activity, it means encouraging functional links between businesses – especially at local and regional level, so that they respond better to the interests of smallholders through functional links with farmers’ organizations, governments and financial investors. We have many examples of such partnerships blossoming now – AGRA for input and credit, and partnerships along growth corridors (as in Beira Mozambique or the Southern Highlands of Tanzania), for safer livestock (including biosecurity to prevent avian influenza in poultry), for specific products (cashews, potatoes or flowers) and to enable producers to get better access to the value of processed products (eg post-harvest cold stores or dairy development).
It means paying special attention to nutrition between conception and the child’s second birthday, reducing the risk of long-term physical and mental impairment through proven interventions.

It means recognizing that there are some nations and regions in which food, water and land insecurity is set to increase particularly as a result of climate change. These situations of protracted food and nutrition security crises are particularly challenging especially as they tend to affect fragile states with less capacity to respond.

We need to make sure that momentum builds up but that the world’s most vulnerable people are at the centre of all our actions. And that means:

a) finding committed leaders who will not rest until all the world’s people enjoy food and nutrition security,

b) ensuring that national efforts are supported by consistent, predictable and coordinated international assistance that reflects best practice in development assistance,

c) catalyzing and nurturing movements that bring together governments, civil society, farmers organizations, the private sector, regional bodies and the international system to work together for food and nutrition security,

d) demonstrating and communicating results so that those who finance such activities can see the results both of their contributions and their hard work to mobilize resources, and backing these efforts with the high quality science that indicates clearly needs and optimal response strategies, taking account of emerging challenges as well as those being faced now. These are all areas in which Canada is at the forefront thanks to the particular focus on food and nutrition together with better access to reproductive, maternal and child health in this G8 presidency year.

It is anticipated that – as a result of these efforts - many more households will be food secure and resilient, less pregnant women and children will be affected by anaemia and other micronutrient deficiencies, fewer children hungry and undernourished between birth and their second year, and this improved food and nutrition security will equip many poor nations for stronger social and economic development.
3. FOOD SECURITY AND IRRIGATION DEVELOPMENT IN CHINA

Zhanyi Gao* and Jinsheng Jia**

ABSTRACT

The food demand in China is continually rising due to population growth. Irrigation has played a significant role in agricultural production and food security due to the uneven distribution of precipitation in both time and space in China. Irrigated agriculture uses 65% of total volume of water supply and produces 75% of total grain production in China. To maintain food security, the irrigated area in China has to be further developed. However, with the rapid economic development more and more water and land resources have been converted from agricultural production to other sectors. Water shortage is an increasing problem for all sectors in China. Furthermore, extreme drought and flood disasters are occurring more frequently due to climate change. Thus, irrigated agricultural production is facing a challenge. The sustainable development of irrigated agriculture has to be based on improving irrigation water use efficiency by taking comprehensive measures at the farm, irrigation district and river basin levels with a different focus at each level. This chapter analyzes and summarizes population increase and grain demand, irrigation requirements for grain production, water supply, irrigation area and distribution and measures for enhancing irrigation development.

INTRODUCTION

China is a developing country with the largest population in the world. Food security is not only important to the sustainable social and economic development of China, but also for its food security and for stable global food prices. China produces food for 21% of the world’s population with only 6% of its fresh water resources and 9% of its farmland.

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China is also a large country in terms of irrigation, which is crucial for agricultural production. In 2008 the total irrigated area in the world was about 276.7 million ha while the irrigated area in China was 57.8 million ha, or 20.9% of the world’s irrigated area. It can be said that China produces the food for 21% of the world’s population with 21% of the world’s irrigated area. In China the yield of irrigated land can be increased by 1 to 3 times compared with rainfed land (Shi and Lu, 2001). In 2008, irrigated area, accounting for 47% of the total farmland, produced 75% of China’s total grain production, and more than 90% of China’s cotton and vegetable production (Li, 2009).

According to the guidelines for food and nutrition developed by the State Council of the People’s Republic of China (PRC, 2001), the average grain holdings in 2010 and 2020 should be 415 and 420 kg per capita per year, respectively. In China food security will be achieved when the average grain holdings reach these levels. However, with rapid social and economic development, people’s living standards and their meat consumption are increasing significantly, putting pressure on the annual per capita grain holdings to rise further.

With the recent economic development more water and land resources have been converted from agricultural production to other sectors. Furthermore, extreme drought and flood disasters are occurring more frequently due to climate change. Thus, agricultural production is facing a challenge. This chapter summarizes the major efforts on food security and irrigation development in China.

### POPULATION INCREASE AND GRAIN DEMAND

Total population and its growth rate are two key factors that affect the demand for cereals in China. Table 1 compares the projections of China’s population by the UN Population Division (UN, 2008) and China’s Population and Development Research Center (PRC, 2000). The average of both projections is used below.

<table>
<thead>
<tr>
<th>Projection (year)</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Nations (UN, 2008)</td>
<td>1.267</td>
<td>1.354</td>
<td>1.431</td>
</tr>
<tr>
<td>China’s Population and Development Research Center (PRC, 2000)</td>
<td>1.269</td>
<td>1.377</td>
<td>1.472</td>
</tr>
<tr>
<td>Average</td>
<td>1.268</td>
<td>1.366</td>
<td>1.451</td>
</tr>
</tbody>
</table>

Based on this near-term population projection and average grain holdings required by the guidelines for food and nutrition development, the Chinese grain demands required by the guidelines for food and nutrition development, the Chinese grain demands in target years is listed in Table 2. Table 3 lists the requirement of domestic grain production and grain imports needed under self-sufficiency rates of 92, 95 and 98% respectively.
Table 2: Grain demands in target years

<table>
<thead>
<tr>
<th>Items</th>
<th>Base year</th>
<th>Target year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000</td>
<td>2010</td>
</tr>
<tr>
<td>Population (billions)</td>
<td>1.272</td>
<td>1.372</td>
</tr>
<tr>
<td>Average grain demand (kg/person .year)</td>
<td>400</td>
<td>415</td>
</tr>
<tr>
<td>Total grain demand (million tons)</td>
<td>509</td>
<td>569</td>
</tr>
</tbody>
</table>

Source: General Office of the State Council (2001).

Table 3: Required grain under different grain self sufficiency rates

<table>
<thead>
<tr>
<th>Target year</th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self sufficient rate (percent)</td>
<td>92</td>
<td>95</td>
</tr>
<tr>
<td>Domestic production (million tons)</td>
<td>524</td>
<td>541</td>
</tr>
<tr>
<td>Import (million tons)</td>
<td>45</td>
<td>29</td>
</tr>
<tr>
<td>Total (million tons)</td>
<td>569</td>
<td>569</td>
</tr>
</tbody>
</table>

Source: General Office of the State Council (2001).

IRRIGATION REQUIREMENTS FOR GRAIN PRODUCTION

The total amount of grain production depends on the following factors: farmland area, crop index, proportion of land for grain crops and cash crops, irrigated area and its yield, rainfed area and its yield, etc. The areas and yields of both irrigated and rainfed cereals can be estimated by analysing development trends and considering major determining factors. Based on the above estimates and potential water resources for irrigation the requirement for efficient irrigation in agricultural production can also be estimated. The logic of the analyzing process is shown in Figure 1 (Gao and Wang, 2008). The year 2000 is used as the base year for the analysis. In 2000 the irrigated area was 55 million ha. The grain crop yield has been increased due to the development of irrigation and improvement of farming practices, seeds, fertilizers, etc. By considering all of these factors, a study was carried out to analyze the requirement for irrigation development in 2010 and 2020 under different self sufficiency rates for cereals (Gao and Wang, 2008). The results of the study are provided in Tables 4 and 5.

Table 4: Requirement for irrigated area in 2010 (Gao and Wang, 2008)

<table>
<thead>
<tr>
<th>Grain self sufficiency rates (percent)</th>
<th>92</th>
<th>93</th>
<th>94</th>
<th>95</th>
<th>96</th>
<th>97</th>
<th>98</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation area (million ha)</td>
<td>55.39</td>
<td>56.49</td>
<td>57.59</td>
<td>58.69</td>
<td>59.79</td>
<td>60.89</td>
<td>62.00</td>
</tr>
</tbody>
</table>

21
Table 5: Requirement for irrigated area in 2020

<table>
<thead>
<tr>
<th>Grain self sufficiency rates (percent)</th>
<th>92</th>
<th>93</th>
<th>94</th>
<th>95</th>
<th>96</th>
<th>97</th>
<th>98</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation area (million ha)</td>
<td>56.92</td>
<td>57.99</td>
<td>58.95</td>
<td>59.97</td>
<td>60.98</td>
<td>62.00</td>
<td>63.01</td>
</tr>
</tbody>
</table>

Therefore, to maintain the grain self sufficiency rate at a level of 95% the irrigated area should reach 58.69 million ha in 2010 and 59.97 million ha in 2020.

Figure 1. Framework for grain production and irrigation development analysis
WATER SUPPLY

Irrigation water in China is supplied from reservoirs, gravity diversion from rivers, pump station lifting from rivers and groundwater pumping. The agricultural water supply from various sources in 2008 is listed in Table 6.

Table 6: Irrigation water supply from various sources in 2008

<table>
<thead>
<tr>
<th>Sources</th>
<th>Volume (billion m³)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water supply from reservoirs</td>
<td>120.76</td>
<td>32.79</td>
</tr>
<tr>
<td>Gravity diversion from rivers</td>
<td>135.84</td>
<td>36.89</td>
</tr>
<tr>
<td>Pump station lifting from rivers</td>
<td>50.77</td>
<td>13.79</td>
</tr>
<tr>
<td>Groundwater pumping</td>
<td>60.90</td>
<td>16.54</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>368.27</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Table 6 indicates that the major source of irrigation water is surface water, which accounts for 83% of the total irrigation water supply. Groundwater only accounts for 16% of total irrigation water supply. For surface water 37%, 33% and 14% are from gravity diversion from rivers, reservoirs and pump lift stations, respectively.

IRRIGATION AREA AND DISTRIBUTION

Influenced by the monsoon, the average annual precipitation in China decreases from 1600
mm in the southeast to less than 200 mm in the northwest (Figure 2) and 80% of the precipitation occurs in four months (June-September).

Of the total water resources in the country, 80% are in the south of China where the land resources represent only 38% of the total. Only 20% of the water resources are in northern China where land resources account for 62% of Chinese territory. These differences in water and land resources highlight the importance of irrigation and drainage for agricultural production. According to the irrigation demand of crops, China may be divided into three irrigation zones: a) intensive, b) supplementary and c) rice paddy (PRC, 1998).

a) The intensive irrigation zone includes northwest China and part of north and northeast China, where annual precipitation is below 400 mm. Here the precipitation and its distribution do not meet crop water requirements and there is hardly any agricultural production without irrigation.

b) The supplementary irrigation zone covers the plain area of the Yellow River, the Huaihe River and the Haihe River and most parts of northeast China. The annual precipitation in this zone varies from 400 to 1000 mm. Influenced strongly by the monsoon, the precipitation in this zone is distributed extremely unevenly. Here crop water requirements change sharply in different years and drainage is essential. Therefore, both irrigation and drainage are highly necessary for stable and high yielding agricultural production.

c) The paddy irrigation zone covers south and part of southeast and southwest China. The annual precipitation in this zone is more than 1000 mm. Paddy rice is the main crop in this zone and irrigation is needed although precipitation is very high. Irrigation is unnecessary for other crops during the rainy season, but is necessary during the dry season. Here drainage and flood protection facilities are the basic condition for stable agricultural production during the rainy season.

Due to the uneven distribution of precipitation in both time and space, irrigation and drainage are the life blood of agricultural production. Up to 2008, approximately 85,400 reservoirs were constructed with a total capacity of 634.5 billion m³. The current annual total water supply capacity of various projects reached 659.1 billion m³. In 2007 the total volume of water used was 581.9 billion m³, with 12.2%, 24.1%, 61.9% and 1.8% used by the domestic, industrial, agricultural sectors, and by the ecological system, respectively. As of now, there are 402 large irrigation schemes each with an irrigated area of more than 20,000 ha. China also attaches importance to the construction of small rainwater harvesting projects (PRC, 2007).

MEASURES FOR ENHANCING IRRIGATION DEVELOPMENT

Establishing a Legal Framework

In China the laws and regulations for enhancing irrigation development include: a) the water
law, b) the law on agriculture, c) the law on the popularization of agricultural technologies, d) the regulation for the management of irrigation schemes, e) the regulation for the calculation, collection and management of water fees, and f) the regulation for the management of subsidy for small irrigation and water and soil conservation projects.

The law on the ‘popularization of agricultural technology’ encouraged the extension of techniques of irrigation and water conservation, soil improvement and water and soil conservation; techniques of water supply and energy utilization in rural areas and agricultural environmental protection; techniques of agricultural meteorology, and techniques of agricultural management and administration (PRC, 1993).

**Implementing Integrated Water Resources Management**

Integrated water resources management (IWRM) at the basin level has become a new model for water resources management. In China irrigation is the largest water user and consumes 60 to 90% of water resources in basins. There is a significant difference in irrigation efficiency and water productivity among the irrigation districts located at the upper, middle and lower parts of river basins because of the variation of natural, economic and social conditions. Usually, the irrigation efficiency and water productivity of the irrigation districts downstream is higher than those of the upstream irrigation districts. However, compared with those downstream the upstream irrigation districts usually receive more water of better quality. Thus, it is necessary to optimize the allocation of water resources at the basin level in order to increase the general water use efficiency and productivity in the whole basin.

**Enhancing Infrastructure for Irrigation and Drainage**

During the past five decades, China has made tremendous achievements in water conservation. Currently, there are 57.8 million ha of irrigated area, accounting for 47.38% of the total farmland of 122 million ha. However, most of the existing irrigation schemes were built before the 1970’s with low design standards and mismatching facilities. After more than 30 years of operation, serious aging problems have emerged, which have resulted in low efficiency and reliability. Since 1998, the rehabilitation and modernization of large-scale irrigation schemes has been carried out with the objective to upgrade 402 large irrigation schemes by the year 2020. The main purpose of the rehabilitation and modernization of large irrigation schemes is to increase their water efficiency and productivity. The rehabilitation of more than 260 large-scale pumping stations for irrigation and drainage is scheduled to be completed by 2012 to 2014. The reinforcement of 6240 large, medium and small-sized reservoirs will be completed by 2010. In the mean time, the amelioration of low-yield farmland will be implemented at a large scale (Chen, 2009).
Adopting Water-saving Irrigation Practices

Currently in China the annual water shortage in agricultural irrigation is about 30 billion m$^3$. Due to social and economic development the demand for water will increase further. To cope with the water shortage and to increase the irrigated area, technologies and measures for saving water in irrigation have been introduced and extended with the objectives of improving the efficiency and productivity of water use.

The efficiency and productivity of irrigation are improved at two levels: farm and irrigation district (Gao, 2005). The technologies and measures for improving efficiency and productivity of water use for irrigation vary at each level because the beneficiaries, the incentives and goals of water saving are different.

At the farm level, small basin, furrow, sprinkler and drip irrigation, land levelling and other measures can be used. For cash crops, micro sprinkler irrigation and drip irrigation can be applied. For field crops, such as wheat and maize the main water saving measures include land levelling, optimal size of basin and furrow, and use of low pressure pipelines. The end users of these water-saving technologies and measures are farmers. They can benefit from water savings by reducing irrigation and labour costs, improving irrigation uniformity, increasing production and labour intensity by adopting water-saving irrigation technologies and measures. Across China on-farm water saving practices were tested in pilot projects in 300 counties and the extension of water saving practices is currently being carried out at nationwide.

At the irrigation district level, the technologies and measures adopted for increasing water use efficiency include canal lining, application of pipelines and improvement of control structures and facilities for water measuring, automation and other technologies for operating irrigation systems. These technologies have been tested in 30 large irrigation districts. The recycling and reuse of water resources in irrigation districts is also practiced at the irrigation district level. It has been proven that recycling and reusing water at the irrigation district is a cheaper and more effective way to increase the efficiency and productivity of irrigation water.

Reforming Irrigation Management Institutions

In China the administration of irrigation management is handled by water resource departments at various levels (Gao, 2009). The structure of an irrigation management system is shown in Figure 3.

At the central level, the Ministry of Water Resources (MWR) takes the responsibility to work out national irrigation development planning, stipulate and modify related regulations, and supervise the implementation of planning and regulations. The Water Resources Bureaus (WRBs) at the province, city and county levels take the responsibility to work out local irrigation development planning and supervise the implementation of planning and
regulations and the management of irrigation schemes. To promote sustainable development and to increase the productivity and profitability of irrigation systems, institutional reforms in irrigation and drainage system management towards a stakeholder-involved management have been introduced.

**Figure 3.** Structure of the irrigation management system

The major stakeholders include the government, the professional irrigation management agency, water user associations (WUAs) and farmers. In China most large and medium irrigation schemes are jointly managed by professional agencies and farmer’s collectives or WUAs. Usually, as a professional agency the irrigation management bureau and its management stations are responsible for the operation and maintenance of the main structures, and the main and branch canals of the irrigation system. The canals below the tertiary canal and small irrigation projects are operated and managed by WUAs or farmer’s collectives. Different roles of the three key stakeholders: the government, irrigation management agents and WUAs must be distinguished.

The role of the government is to provide leadership, to design national development planning, to stipulate and modify policy and legal arrangements and related regulations, to supervise the implementation of planning and regulations, to stipulate make and modify institutional arrangements, to strengthen capacity building, to make financial arrangements and to appraise existing irrigation systems.

The tasks of irrigation management agents are to evaluate and benchmark the operation of irrigation systems, to conduct feasibility studies and develop designs for rehabilitation, to carry out rehabilitation of the main canals and structures of irrigation systems, to implement institutional reform, to operate and maintain the main structures and canals systems, to bridge the gap between the government and WUAs, to provide technical support to WUAs, to supervise and monitor irrigation systems, to document the operation
of irrigation schemes and to test and introduce new technologies and materials.

The responsibility of WUAs is to carry out the rehabilitation as well as to operate and maintain farm canals and structures and provide irrigation services to individual water users. Since 1995, when the first farmer WUA was established in the Zhanghe irrigation district of Hubei province, participation of irrigation management has been adopted in 30 provinces and autonomous regions in China. Currently, there are more than 20,000 such water user associations and cooperative organizations which involve 60 million farmers. The irrigated area managed by water user associations has reached 6.67 million ha (Pei, 2009). It has been proven that participatory irrigation management is an effective measure to increase water efficiency and productivity of irrigation, especially for China’s specific conditions of many small land plots per household.

**Strengthening Protection of Groundwater Use**

In China groundwater has played an important role in irrigation and in domestic and industrial water supply, especially in dry years. Groundwater will play an even more important role under climate change. To achieve sustainable exploitation and use of groundwater, it is important to protect the groundwater through reasonable exploration, use and adequate recharge measures. The new ‘Water Law’ highlights the integrated surface and groundwater management.

**Strengthening the Construction of Small-scale Water Conservation Projects and Use of Poor Quality Water**

To cope with problems of water shortage and climate change, the construction of medium, small and micro-size projects, including rainwater harvesting and utilization projects, have been developed in China, especially in the northwest and southwest. The treatment and application of poor quality water is also practiced in line with local conditions. Currently, there are 4.2 million small water storage ponds and rainwater harvesting wells for supplying drinking water and 7 million small water storage ponds and rainwater harvesting wells for irrigation purposes.

**Encouraging International Cooperation**

Facing the floods, droughts and water shortages caused by climate change, the research on adaptation strategies and long-term development planning are being carried out with the support of different levels of government. Much experience and progress has been gained with integrated water resources management and through the application of advanced technologies. China has attached great importance to international cooperation on research to cope with climate change.
CONCLUSIONS

The food demand in China is continually rising due to population growth. Irrigation has played a significant role in agricultural production and food security due to the uneven distribution of precipitation in both time and space. Climate change has and will continue to have a big impact on the supply and demand of water resources, as floods and droughts occur more frequently. Extreme droughts and floods caused by climate change have a major impact on agricultural production. To maintain food security at a self-sufficiency rate of 95%, the irrigated area in China should reach 58.69 million hectares in 2010 and 59.97 million hectares in 2020.

To solve the problem of water shortage and to cope with climate change, measures are being undertaken to improve the use of irrigation water by enhancing the efficiency at the farm, irrigation district and river basin levels with a different focus at each level. Related laws and regulations have been passed and modified. Integrated water resource management will be an effective measure to cope with climate change and water shortage.

Most of China’s existing irrigation schemes were built before the 1970’s, and the rehabilitation of these irrigation schemes is an effective measure for coping with climate change and ensuring food security. China has launched the rehabilitation and modernization of large irrigation schemes, and this work is scheduled to be completed by 2020. Reform of the irrigation management institutions is an important component of the modernization of irrigation schemes and has been successfully adopted in China.

Measures have been undertaken to strengthen the protection and utilization of groundwater and allow for reasonable exploitation. Medium and small projects, including rainwater harvesting and utilization projects have also been developed to cope with water shortage and climate change in China.

REFERENCES


4. COMBATING HUNGER AND POVERTY IN THE TROPICAL DRYLANDS OF ASIA AND AFRICA

William D. Dar*

ABSTRACT

The tropical drylands are characterized by extreme rainfall variability, recurrent and unpredictable droughts, flooding, warm temperatures and a fragile natural resource base with inherent low fertility soils. Crop production is low and over 45% of the world’s hungry people live in these regions. Climate change, growing populations, poor development infrastructure, increasing land degradation and water scarcity make achieving food security in the tropical drylands a daunting challenge. However, success stories from throughout the region show that under optimal water, land and crop management, crop yields and farmers incomes can be substantially increased. Innovative research and development strategies that address natural resource management carried out in partnership with farmers and other stakeholders, and integrating policy, marketing and support services, can address problems of poverty, food insecurity and environmental degradation and bring prosperity to the tropical drylands.

INTRODUCTION

The semi-arid tropics or tropical drylands span 6.5 million square kilometers covering over 55 countries and are home to more than 2 billion people (Figure 1). Over 45% of the world’s hungry and more than 75% of its malnourished children live in this region (Wani et al. 2009). The majority of poor live in rural areas and depend on agriculture for their livelihoods.

* Director General, International Crops Research Institute for the Semi Arid Tropics
The tropical drylands have a challenging and inhospitable terrain where agriculture is risky. Characterized by extreme rainfall variability, recurrent and unpredictable droughts, flooding, warm temperatures and a fragile natural resource base with inherent low fertility soils, the rising perfect storm -- a confluence of climate change, desertification, biodiversity loss, price rise, and mounting poverty and population -- further threatens to disrupt the lives of the poor who depend on agriculture for survival.

With an annual linear rate of population growth of 1.6% in the drylands, there will be about 115 million more mouths to feed between now and 2020; 46 million in Africa’s drylands and 69 million in Asia’s. The expanding population and accelerating use of natural resources is resulting in increased natural resource degradation. Achieving food security under these conditions is a daunting challenge, but it also represents an opportunity. As Dr Norman Borlaug, a central figure in the ‘Green Revolution’ said, “The yield potential is there, but you can’t eat potential.”

Agricultural production in the tropical drylands is predominantly rainfed. Rainfall generally occurs in short, torrential downpours and much of this water is lost as surface runoff, evaporation or deep drainage (Pathak et al. 2009). Rainwater use efficiency is therefore low (35–45%) and over the long term, the runoff results in extensive loss of precious, nutrient-rich topsoil. In addition, groundwater levels in the tropical drylands are being depleted and most rural rainfed areas are facing general water scarcity and drinking water shortages during the summer months (Pathak et al. 2009).
In temperate, humid or subhumid regions of the world, rainfed agriculture produces very high yields (5-6 t/ha), but in farmed lands of the semi-arid regions, yields average only 1-1.5 t/ha (Wani et al. 2009). Drought, dry spells and land degradation are the main causes of low crop production and poverty in the semi-arid regions. Droughts cause crop failures and short dry spells during the growing season reduce crop yields. The high risk of losing part or all of a crop makes farmers unwilling to invest in inputs and land management and the resulting poor use of agricultural lands results in increased soil loss due to wind and water erosion, nutrient depletion, salinization, loss of vegetation cover and reduced biodiversity.

Agriculture in the semi-arid tropics has long been viewed with pessimism and hopelessness. Tropical dryland areas are usually seen as resource-poor and perennially beset by shocks such as drought, trapping dryland communities in poverty and hunger, making them dependent on external aid. However, dryland farmers are ingenious and resourceful and recent yield gap analyses carried out for major雨fed crops of the region revealed that farmers’ current yields were two to four times lower than yields achievable under optimal water and management (Singh et al. 2009a; Wani et al. 2009) (Figure 2, blue columns). By applying scientific innovations backed by adequate policy, marketing and other support services, farmers are able to increase their crop productivity and incomes several-fold, while improving the resilience of their lands and livelihoods. Thus, there is hope of prosperity in the tropical drylands.

MANAGING WATER TO OVERCOME SCARCITY

Given the persistent problems of drought and water scarcity in the drylands, water shortages must be addressed by utilizing natural resource management principles and techniques to improve moisture content, fertility, soil depth, organic matter, and rainwater utilization through watersheds and water conservation and by employing plant breeding and biotechnology research to improve water-use efficiency and drought tolerance in crop genotypes.

In the tropical drylands, seasonal rainfall is generally adequate to significantly improve yields but managing the extreme rainfall variability in time and space is a tremendous challenge (Wani et al. 2009). Rainfall is seasonally variable and characterized by few rainfall events, high intensity storms and a high frequency of dry spells or droughts. Managing water and using it efficiently are the main yield determinants. Droughts result in complete crop failure which cannot be prevented by agricultural water management and must be managed by other means such as food storage, livestock sales or grain banks. Short dry spells occurring during the growing season, however, can be bridged using improved land and water management. Water harvesting, supplemental irrigation and community watershed management are all tools that can lead to improved crop production and local food security.

Water Harvesting

Water harvesting, an age-old practice which collects and stores surface runoff and uses it to irrigate crops during dry spells, can stabilize crop production and alleviate the risk associated
with unpredictable rainfall. Water harvesting systems include catchment areas that range from a rooftop to several square kilometers of land where runoff occurs and a storage facility such as a tank or a pond collects and holds the runoff water. Successful implementation of water harvesting requires data on rainfall, soil, relief, cropping systems, and local socio-economic conditions in order to minimize soil erosion, habitat loss and water conflicts (Oweis and Hachem, 2009).

**Supplemental Irrigation**

Combining water harvesting with effective irrigation technology can result in significant water productivity improvements. Inexpensive and simple irrigation systems have been developed to save labor and optimize the use of water for row crops on small plots (Singh et al. 2009b). For example, Bucket Kits include a simple 20-liter household bucket (often replaced with a polythene bag) attached to a pole at about shoulder-height and equipped with drip tapes to water a kitchen garden or larger Drum Kit systems with a 200-liter drum with lateral lines and micro tubes to irrigate a 125 m² plot. Low-head drip irrigation technology using drip tape has proved useful in sloped and uneven fields and has a high water use efficiency. Supplemental irrigation at a rate of 60-80mm doubled and even tripled grain yields in Burkina Faso and Kenya, although the most beneficial effects of the irrigation were obtained only in combination with soil fertility improvements (Rockström et al. 2003).

**Community Watershed Development**

Management of natural resources at the watershed scale increases food production, improves livelihoods, protects the environment, addresses gender and equity issues and is considered an engine of growth for development of fragile rainfed areas (Joshi et al. 2009). In the past, improved watershed management was generally synonymous with achieving a particular, often single technical objective, e.g. improved forestry, better soil conservation, or the introduction of water harvesting and was initiated and executed with little or no real involvement of farmers. A new approach regards watershed development and management in its entire complexity, where inter-related factors and their interactions are considered with the main objective of poverty alleviation and food security of watershed communities (ICRISAT, 2011). Partnerships draw on expertise from research organizations, NGOs, agricultural universities, and local governments but retain farm households as key decision makers. With the new emphasis on poverty alleviation and food security through appropriate natural resources management, both people and natural resources become the primary focus. Conservation and harvesting of rainwater to augment surface and groundwater, management to improve soil quality (use of fertilizers, crop residues, composting and crop diversification with legumes), wasteland development and tree planting, use of high-yielding varieties, introduction of integrated pest management to reduce pesticide as well as training farmers and other stakeholders in new technologies and approaches are all used together to increase food production in the watershed (Joshi et al. 2009).
Participatory and knowledge-based watershed development programs in Andhra Pradesh, Gujarat, Madhya Pradesh, Rajasthan and other states in India and parts of southern China, northern Vietnam and northeast Thailand have shown that farmer and public investment can provide attractive social returns leading to poverty reduction. The success of the Adarsha Watershed model in Kothapally in Andhra Pradesh, India has attracted farmers, policymakers and development investors (Sreedevi et al. 2004). Income-generating options for the landless and women at Kothapally and other benchmark watersheds have included the setting up of village seed banks through self-help groups; value addition through seed material; product processing such as dhal making, grading and marketability; poultry rearing for egg and meat production and vermi-composting. An average household income of US$ 1066 was generated from crop diversification and other systems in the watershed compared to US$ 734 in the non-watershed, reflecting an increase of 45% due to watershed interventions.

Similarly, the Lucheba watershed in Guizhou province in China saw improved productivity with the adoption of cost-efficient water harvesting structures, farming system diversification and intensification from rice and rapeseed to tending livestock and horticultural crops. Following watershed interventions, mainly growing vegetables and other diversified activities like tending chicks and pigs, the average income of farmers increased threefold, from US$ 462 (before the interventions) to US$ 1538. The development of community watersheds in China and India has resulted in crop yields increasing up to four-fold and incomes rising by 45% and 77%, respectively.

CROP IMPROVEMENT AND DIVERSIFICATION

Sustainable growth in crop production, farm income, food security and environmental protection can be achieved through the development of improved and diversified cultivars, eco-friendly and cost-effective pest management practices, efficient seed supply systems, and commercialization of diversified and alternative uses of crop produce. Chickpea, groundnut, pigeonpea, sorghum and millet are all drought-resistant and nutritious crops that are well-suited to the semi-arid tropics and work is being carried out to increase adoption of improved varieties by farmers through formal and informal seed-supply chains and systems, and to develop institutional mechanisms between public and private sector stakeholders to ensure sustainable demand for public sector-bred improved varieties (ICRISAT, 2011).

Recognizing the potential of agricultural biodiversity and the services it provides will be key to meeting future food needs while maintaining and enhancing the other goods and services provided by agricultural ecosystems, such as clean air and water (Waliyar et al. 2002). Diversification of crops cultivated by smallholder farmers in the semi-arid tropics has the potential to increase household income, create a more nutritious household diet and provide remunerative labor opportunities as well as valuable by-products such as firewood, fibre and fodder. Crop diversification by introducing legumes into rice/wheat fallows pursued in the Indo-Gangetic plains of South Asia, growing medicinal and
aromatic plants in partnership with private sector companies and systems diversification through mixed crop-livestock systems have served as coping strategies against risk and also enhanced incomes. Crop residues of chickpea, groundnut, pigeonpea, sorghum and millet are important sources of animal feed throughout the year, notably in the dry months when other feed resources are scarce. Improving the digestibility of such crop residues can have a significant impact on milk production, particularly in South Asia. For example, haulm or stems of a groundnut variety led to a 20% increase in milk yield of dairy animals of farmers adopting the improved variety in Andhra Pradesh (ICRISAT, 2009).

The African Market Gardens (AMGs) concept combines low pressure drip irrigation systems with high-value crop diversification, enabling the commercial integration of fruit, vegetables and trees in the dry Sahel. These small “market gardens” can be tended by women’s groups to both increase their incomes and diversify their family’s diet, multiplying their annual incomes by several-fold, in some cases more than 10-fold to US$ 1,500 from an area of only 500 square meters.

**Crop Breeding**

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has a genebank in India that holds 120,000 accessions of chickpea, pigeonpea, groundnut, sorghum, pearl millet, and six small millets from 144 countries. The collection serves as insurance against genetic erosion and as a source of resistance to diseases and pests, tolerance to climatic and other environmental stresses and improved quality and yield traits for crop improvement. It has distributed over 1.3 million samples to scientists in 144 countries, and 66 accessions have been directly released in 44 countries contributing to global food security. Development of new varieties and cultivars of the crops and their introduction to local smallholder farmers in India has resulted in increased crop production and yields and improved crop quality.

**CLIMATE CHANGE**

Climate change predictions point to warmer temperatures in the tropical drylands and shorter growing seasons, increased drought frequency and changing rainfall patterns in many regions (IPCC, 2007). ICRISAT studies have generated a “hypothesis of hope” (Figure 2) which provides optimism that the impacts of climate change on yield under low input agriculture are likely to be minimal. The average crop yield grown under the current climate (blue columns), show that a massive yield improvement is possible by improving agronomic practices and germplasm. Even under conditions of climate change (red columns), strong yields are still possible if farmers combine improved practices with climate-adapted crop varieties.
To cope with the impacts of climate change on reduced length of crop growing season, crops that are adapted to heat and high soil temperatures, knowledge and understanding of photoperiod-sensitive flowering, information on genetic variation for transpiration efficiency, short-duration varieties that escape terminal drought and high-yielding and disease-resistant varieties will all be valuable tools to improve crop production. Short-duration chickpea cultivars that can withstand high temperatures, pearl millet flowering at 40+°C and a short-duration groundnut cultivar that escapes terminal drought are some examples of resilient crops for the poor.

**LINKING FARMERS TO MARKETS**

Developing countries in Asia and Africa are witnessing a fundamental shift in agriculture from farming for household consumption to a more market-oriented production, where consumer-driven supply chains will play a dominant role unlike the erstwhile product-oriented supply chains. Thus, procurement and marketing of agricultural commodities are witnessing institutional innovations like contract farming, bulk marketing through producers’ associations, direct marketing, marketing through cooperatives or specialized middlemen and ICT-enabled supply chains that directly link the producer to the end user.

Linking smallholder farmers to input and output markets and other actors along the value chain that include credit agencies, assemblers, wholesalers, transporters and finally the consumer/end user is essential for success. For example, in Malawi, groundnut producers...
are assured markets through the 100,000-member strong National Smallholder Farmer Association of Malawi (NASFAM), which provides agricultural advisory services for groundnut production.

**EMPOWERING WOMEN**

The majority of farmers in the dryland tropics are women and therefore it is necessary to engage women as leaders in farmer-to-farmer knowledge-sharing and training activities in areas such as crop management, participatory plant breeding, crop processing, marketing and agro-enterprise development. Helping women’s groups to gain access to the seed and skills that they need to grow and export high-value crops improves women’s incomes and directly benefits household nutrition. In Niger, for example, a group of 120 landless women in the Dosso region started growing hardy indigenous vegetables in degraded land on a 7 hectare field in June 2006. Micro-catchments (demi-lunes) were built to catch and store runoff rainwater and between the demi-lunes, planting pits were dug to place manure and the plant. The degraded area has grown to 70 hectares of lush and productive greenery. Women are additionally using crops such as a new short-duration okra cultivar jointly developed by AVRDC. At present, 5000 rural women and their households are benefiting from these technologies.

Women also capture most of the profits from market gardens established in Niger since they dominate vegetable production and marketing. Market gardens producing improved tomato, onion and other vegetable varieties have proved highly profitable, giving annual returns of up to US$1,500 from an area of only 500 square meters. For the first time ever, markets in the nation’s capital, Niamey, were well supplied with tomatoes in the 2009 rainy season.

**ENHANCING IMPROVED SEED AND FERTILIZER AVAILABILITY**

The availability of quality seed is the foundation for food production and productivity and a precursor to crop and food diversification. Although research has developed new stress-tolerant crop varieties that are well-adapted to smallholder farms, many farmers lack access to improved seed and continue to recycle old seed that has been exhausted after generations of cultivation. Yields have remained poor, contributing to food insecurity. To overcome such limitations, it is necessary to develop local seed companies by supporting breeders in national breeding programs to develop and release improved varieties of a range of food crops; establish a network of agro dealers; support new and existing seed companies to produce and market improved quality seed and support seed trade harmonization at the regional level. For example, the West Africa Seed Alliance (WASA) is working towards the establishment of a sustainable commercial seed industry capable of ensuring that small-scale farmers have affordable, timely and reliable access to adapted genetics and traits in high quality seeds and planting materials. Through a baseline survey in the Dosso region of Niger, 22 farmer associations and individual women farmers were identified as local seed producers and traders. They were selected and trained through WASA and today, more 135 farmers (including 86 women) are involved in the seed business. In India, ICRISAT encourages and
helps smallholder farmers to go into the production and storage of self-pollinated varieties of legumes since the private seed sector is not active in seed production.

Smallholder farmers often have little access to fertilizers or cannot afford them. Providing small packs of fertilizers of various sizes improves access in two ways: first, it is affordable to many who cannot meet the full cost of the traditional 50 kg bags and, second, it creates convenient access to farmers as the fertilizer can be more easily sent to a depot close to them (Minde et al. 2008). Novel outreach approaches in Africa using mechanisms such as micro-credit, vouchers systems, and precision use of fertilizers are also helping farmers to access and utilize seed to maximize their incomes.

INCLUSIVE MARKET-ORIENTED DEVELOPMENT (IMOD): THE NEW WAY FORWARD

Dryland poverty rates are declining in Asia, but not in sub-Saharan Africa. Analyses by the World Bank and ICRISAT have found that access to markets is key to escaping poverty. Gleaned from its rich knowledge base spanning 38 years in partnership with institutions, strategic studies, long-term village-level studies, as well as global studies by the World Bank, ICRISAT has adopted Inclusive Market-Oriented Development (IMOD) as a guiding framework of its new Strategic Plan to 2020 to empower smallholder farmers to grow their way out of poverty. IMOD is a socio-economic process and a dynamic progression from subsistence towards market-oriented agriculture which will achieve a new level of access to resources, stability and productivity for poor smallholder farmers (Figure 3).

**Figure 3.** Inclusive market-oriented development (IMOD), the unifying conceptual framework for ICRISAT’s Strategic Plan to 2020
IMOD starts by increasing the production of staple food crops, converting deficits into surpluses that are stored or sold into markets. Stored food provides a buffer in times of hunger, and higher incomes make it possible to purchase more food when needed. Income enables the poor to purchase inputs such as seed, fertilizer, labour, tools, livestock, insurance and education. These inputs raise farm productivity and prosperity further and enable another round of investment and productivity growth, creating a self-reinforcing pathway out of poverty. This forms the crux of IMOD.

To pursue this pathway to prosperity, ICRISAT will employ a systems perspective in setting its priorities to ensure that all important issues are addressed holistically. At a macro level, systems thinking allow ICRISAT to study the interaction of various economic, social, political, physical and technological factors influencing tropical dryland agriculture. At a micro level, this perspective is valuable in viewing how things influence one another within a dryland farming system. This perspective enables ICRISAT to plan, implement and evaluate its research programs for optimum impact along the whole dryland agriculture value chain.

CONCLUSIONS

Agriculture in the dryland tropics is predominantly carried out by smallholder farmers on land that has an unreliable supply of water and is nutrient poor. A lack of social services and development infrastructure further restrict farmer incomes and result in extensive food insecurity. There are, however, many tools that the resourceful and experienced farmers of the tropical drylands can put to good use if given the opportunity to participate in community development and capacity building. Water harvesting, supplemental irrigation, providing access to micro-credit, quality seeds and inputs, diversifying crops, developing storage and processing facilities and expertise, and linking farmers to markets will all lead to increased crop production and farmer prosperity. Inclusive market-oriented development (IMOD), a unifying conceptual framework developed by ICRISAT, incorporates all these tools in the planning, implementation and evaluation of its research programs for optimum impact along the whole dryland agriculture value chain. Significant reductions in poverty and increases in food security in the dryland tropics are possible.

REFERENCES


The Asian region has not only the highest share of the world’s irrigated area (70%), but also the largest proportion of world’s population to feed (60%). Forecasts suggest that in coming decades most of the expansion of global irrigated area will take place in Asia and therefore today Asian irrigated agriculture is facing the triple challenges of developing water resources, expanding irrigated area with least environmental impacts, and increasing food production with progressively diminishing water supplies. Improved technologies play a significant role in achieving water savings, enhancing the operation and maintenance of irrigation, and overall gains in irrigation performance and food production. There is a vast range of technologies, from simple siphon tubes for field water application to sophisticated canal automation and telemetry. These technologies can be categorized as: off-farm, on-farm, and soft tools for both off-farm and on-farm. Despite the availability of a wide spectrum of irrigation technologies, there are technical, economic, social and institutional issues involved in their wide scale adoption in the Asian region. This chapter highlights some strategies and recommendations to fully explore the potential benefits of these technologies in the irrigated agriculture of Asia. This includes developing appropriate and affordable technologies and their effective dissemination, capacity development and training of irrigation managers, field staff and farmers, and enhancing investment/funding by national governments, the private sector, and international financing institutions.
INTRODUCTION

Increasing food production with diminishing water supplies and a changing climate requires innovative measures and new technologies for irrigated agriculture. Despite undeniable past success in contributing to food production, there has been a discernible decline in the performance of some irrigation projects especially in Asia where traditional practices engage vast manpower resources in widely spread rural settings. This decline will need to be reversed given the need to double food production to meet increasing demands by 2050. This is particularly challenging in Asia, where 2/3 of the global population resides.

Despite remarkable recent advances in new technologies to improve irrigation and drainage practices, their widespread adoption, backed by financial and other necessary supports, is yet to occur. Irrigated agriculture competes for low-cost, quality water. Affordable innovations, tailored to local conditions and adaptable by resource-poor farmers are as important as modernization of major irrigation diversions with a focus on production. A combination of factors including physical, institutional, legal, governance and policy changes can yield better water productivity and lead to greater food security.

Many countries in Asia are extending incentives for farmers to adopt water-saving irrigation technologies. The main pathways for enhancing water use efficiency (WUE) in irrigated agriculture are to increase the crop biological output per unit of water (engineering and agronomic management aspects), reduce water losses, reduce water degradation (environmental aspects), and reallocate water to higher priority uses (societal aspects).

IRRIGATION FOR FOOD PRODUCTION IN THE ASIAN REGION

The Millennium Development Goal 1 (MDG1) that aims to reduce the world’s hungry by half is significant to the Asian region, with its high number of malnourished people. The challenge of ensuring food security has increased due to new external drivers that are...
influencing management decisions. Such drivers include climate change, the economic downturn, world trade and tariffs and the competition of biofuel for land and water\(^1\). The importance of these drivers in affecting water decisions is highlighted in the World Water Development Report 3 (WWAP, 2009).

Although the Asia-Pacific region accounts for 60% of the world’s population, it shares only 35% of the world’s arable land. The region has the largest share of the world’s irrigated area (70%) and also the highest proportion of irrigation water withdrawals (86%) (Annex 1). Growth of irrigated area in Asia during the last four decades is shown in Figure 1.

Irrigated agriculture acts as an engine of socio-economic growth by reducing poverty and boosting rural growth. With the advent of improved agro-technology and assured irrigation water availability, yield levels, especially for cereals have shown an upward shift in many Asian countries (Figure 2). Yet there is still a significant yield gap to be bridged to reach potential crop yield levels.

In order to feed the extra 1.5 billion people in Asia in 2050, expansion of the irrigated area by 10% will be required (Mukherji et al. 2009). This will call for substantial additional withdrawals of water, a stress reflected in the thematic discussions by a consortium of global water related organizations which contributed to the World Water Forum 5 in sessions focusing on ‘Water and Food for Ending Poverty and Hunger’, covered under the theme ‘Advancing Human Development and Millennium Development’ (ICID, 2009).

\[\text{Figure 2.} \text{ Rice productivity trend in some major Asian rice growing countries}\]

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1\ ICID, as coordinators of a consortium of 54 partners (with an additional 19 consultation partners) had wider consultations on different aspects of the subject. The recommendations at the end stressed the need for doubling the food production by 2050 for feeding the world’s population and emphasized the importance of irrigated (and drained) lands in contributing to the production objective.
Asian irrigated agriculture faces the dual challenges of enhancing the efficiency of irrigated agriculture to obtain maximum productivity, as well as developing further water resources through additional storage and new areas to be brought under irrigation.

PREVAILING IRRIGATION TECHNOLOGIES

There is a vast range of technologies available for improved operation, better management and efficient use of irrigation water ranging from simple siphon tubes for field water application to sophisticated canal automation and telemetry. These technologies can be categorized as: off-farm, on-farm, and soft tools for both on-farm and off-farm.

**Off-farm Technologies**

Water is conveyed from its source (storage reservoir, river, or well) to the field head and subsequently applied to crops. This conveyance distance could be several hundred kilometers from the source (in large scale canal irrigation schemes), to a distance of few hundred meters (in small scale schemes). The objective of the conveyance system is to deliver irrigation water from the source to fields at the desired flow rate, at pre-decided times and locations in the command area with minimum losses. Technologies have been developed to achieve this objective through improved operation, regulation/control and in distribution of water over the command area. These include canal lining (both conventional concrete or stone, as well as geo-textiles), upstream/downstream controls, Supervisory Control and Data Acquisition (SCADA)\(^2\), Total Channel Control (TCC) (Box 1), improved flow measuring and regulating devices, the use of telemetry, modern water delivery outlets, en-route storages / night storage reservoirs etc.

**On-farm Technologies**

Once the water reaches at the farm/field head from its source, it is applied through variety of methods/systems to the crop. These can broadly be classified as gravity or surface methods, sprinkler, and micro-irrigation. Worldwide, the gravity system is the most dominant method adopted on about 244 million ha (86% of total irrigated area), while sprinkler irrigated area is about 32 million ha (11%), and micro-irrigated area is about 8 million ha (3%).

Gravity/surface methods include furrows, borders, and basin layouts. Sprinkler systems cover a range of equipment from a conventional portable system to modern linear move, centre pivot, and reel move systems. Micro-irrigation is a low flow, low pressure precision irrigation system and comprises drip (surface and subsurface), line source/ tapes, micro jet, bubblers, foggers, and micro sprinklers. Normally, the field application efficiency is higher as one moves progressively from surface methods to sprinkler and to micro-irrigation. There

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\(^2\) SCADA refers to a system that collects data from various sensors at (remote) locations like an irrigation district control office or a factory or plant and then sends this data to a central computer. This then manages and controls the data.
**Box 1. Australia Invests in Irrigation Technology**

In Australia, irrigation is the largest consumptive user of water, and like most other places in the world it is fairly inefficient in the delivery of water to fields. The average off-farm efficiency (from storage to farm) and the system efficiency (from storage to plants) of large irrigation schemes in Australia are about 70% and 50%, respectively. The Australian government has allocated $AUS12 billion to invest in water projects and programs with the idea of making the environment healthier.

The Goulburn-Murray Irrigation district (GMW) had water entitlements of 1.7 billion cubic meters (BCM). In a normal year it used 2 BCM for which 3 BCM had to be released to deliver this amount of water. The Victorian State Government commenced a major project in 2002-03 using Total Channel Control (TCC) as new irrigation management technology. This technology was further developed and rolled out across the entire 6,500 km long GMW channel network. The Victorian Government announced additional modernization projects in 2006, 2007, and 2008 to save an estimated 500 million cubic meters of water to be shared equally among the environment, the irrigators and the Melbourne urban community. The investment was based on the premise that delivery efficiency could be increased from 70% to 85%.

Thus the 6,500 km of GMW channels will be reduced to a backbone channel network of 2,400 km with a fully automated channel system operated from a central location, 600 km will be lined to prevent seepage in lighter soil types and there will be some gravity fed pipelines to replace some of the smaller channels. The backbone upgrade is expected to cost about $AUS 600 million.

About 60% of farm outlets will be connected directly to the backbone channels and the rest of the farms will be connected to the backbone by privately owned infrastructure. This is a major change and complements on-farm changes that have been occurring over a long period. Farms have been getting larger through amalgamation of adjoining properties for some time. The biggest change however is farm irrigation practices. Most of the irrigation systems are gravity irrigation systems and with all the focus on greenhouse gas emissions farmers are reluctant to become big energy users. The importance of maintaining the gravity element of the system has seen the development of new on farm irrigation techniques.

As part of the upgrade every Dethridge meter wheel will be replaced to comply with Australian Standards. The old Dethridge meter wheels measured in favor of the farmer by about 8% but could only deliver flow rates of 5 or 10 million liters /day. The new meters are electronic and can deliver flow rates of up to 25 million liters/day. Farmers are also using a new irrigation system “Super fast surface irrigation”. The irrigator puts the entire flow down one irrigation bay and irrigation times have been reduced dramatically as the water doesn’t have time to penetrate beyond the root zone. The Australian Government has allocated another $AUS300 million to support the on farm irrigation changes which are needed to maintain the productive capacity of the region.

Typical investment costs and area coverage of various technologies in the Goulburn – Murray Irrigation District are shown below:  

<table>
<thead>
<tr>
<th>Type of Technology</th>
<th>Area covered (ha)</th>
<th>Cost/ ha (AU $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canal automation with SCADA</td>
<td>204,506</td>
<td>627</td>
</tr>
<tr>
<td>Canal lining with - HDPE</td>
<td>3,702</td>
<td>4048</td>
</tr>
<tr>
<td>- concrete</td>
<td>564</td>
<td>4468</td>
</tr>
<tr>
<td>- geo-textile/ beaching</td>
<td>23,768</td>
<td>142</td>
</tr>
<tr>
<td>Piped conveyance of irrigation water</td>
<td>11,803</td>
<td>6,490</td>
</tr>
<tr>
<td>Modern water delivery outlets (Flume gate/ Magflow/ PA)</td>
<td>117,054</td>
<td>481</td>
</tr>
</tbody>
</table>

Source: Data received from Australian National Committee of ICID (ANCID)

The Pilot of TCC on the CG2 has demonstrated that open channels can be fully automated and customer service can be greatly improved by maintaining constant flow rate. It facilitates accurate measurement of flow at each regulating structure and water losses can be better understood and located, thus providing opportunity to reduce leakages, seepage and poor operation of flow control devices.

Source: ANCID / also inputs from Stephen Mills, ANCOLD in a communication to ICID Central Office, 2009
has however, been a significant increase in application efficiency of surface methods. Field channels are being replaced by piped conveyance systems using thermo plastic pipes and lay flat pipes. Furrow and basin layouts on laser graded fields can achieve comparable efficiency to the sprinkler method. Siphon tubes, gated pipes and solar power operated surge valves and cable-gation have further enhanced the application efficiency of surface irrigation methods.

As irrigation water availability dwindles, farmers in many countries, especially in arid and semi-arid countries are opting for sprinkler and micro-irrigation systems with the latter preferred in water scarce areas and for growing high value/cash crops. Using micro-irrigation as well as optimum use of other inputs like fertilizers, nutrients, pesticides, energy and labor, farmers are able to increase crop yields and expand their irrigated areas from the saved water. Drip irrigation is also an ideal method for efficient and safe use of treated wastewater for irrigation (ICID 2008a). In the Asian region, China and India are at the forefront of adopting sprinkler and micro-irrigation, covering about 20% of the world irrigated area by these methods. Dramatic growth in expansion of micro-irrigation in India is a typical example of enabling policy support of the federal government and successful public-private partnerships (Box 2).

Besides the steady expansion of the commercial/conventional sprinkler and micro-irrigation systems which require relatively high investment and additional skill for their operation and maintenance, low cost systems have been developed which are in reach of smallholders and poorer farmers and have resulted in significant adoption (Ghinassi, 2008).

Another area where on-farm irrigation technology has made its impact is irrigation scheduling. Water is applied as per the crop requirement at the desired time intervals and duration. Scheduling tools like irrometers and tensiometers, wetting front detectors, and remotely operated soil moisture sensors and automatic weather stations are increasingly used in developed countries. However, despite the commercial availability of these scheduling tools, they are yet to become popular amongst most Asian farmers.

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**Box 2. Micro-irrigation Development in India**

India has the largest irrigated area (60.9 million ha as net) in the world. Of this, 60% is irrigated from groundwater, 25% from canal water and 15% from tanks and other sources. In the last five decades, groundwater irrigation has dramatically increased seven fold. Irrigated agriculture plays a crucial role in achieving India’s food security and is the main source of income and livelihood for the vast rural population. Water withdrawal for irrigation in the year 2000 was 541 BCM (85.3 % of total water withdrawals). The Ministry of Water Resources (MOWR) estimates irrigation withdrawals for the years 2010, 2025 and 2050 at 688 BCM, 910 BCM, and 1072 BCM, respectively. With the growing competition from domestic and industrial sectors, future irrigation will have to be managed with decreasing water supplies. Governments have been promoting sprinkler and drip irrigation technologies for three decades enabling farmers not only to cope with looming water scarcity but also to expand their irrigated areas.

In India, micro-irrigation technology was introduced on a commercial scale in 1985, with area coverage of only 1000 ha. The micro-irrigated area grew by leaps and bounds to 0.035 million ha in 1990, 0.153 million ha in 1995, 0.351 million ha in 2000, 0.5 million ha in 2005, and1.6 million ha in 2009. This dramatic growth in micro-irrigated area is attributed to various factors like liberal subsidy support and a favorable policy environment by the Central and State governments, extensive research and development in academic and research institutes, a strong manufacturing base, a well developed pump and pipe industry, a wide network of system suppliers, government promotion of horticulture
and plasticulture, and farmer capacity building and training. The Central and State Governments together provide a subsidy of 50 to 70% of the investment cost of the micro-irrigation systems to farmers. The Government of India has provided US$ 667 million to bring an additional 1.5 million ha under micro-irrigation and 1 million ha under sprinkler irrigation during the 11th Five Year Plan (2007-12). This translates into almost US$ 2 billion of business for the Indian irrigation industry.

The Ministry of Agriculture (2009) carried out an evaluation of the Centrally Sponsored Scheme (CSS) on Micro-irrigation to assess its impact on crop productivity, irrigation water use efficiencies, savings in input use and labor use, as well as its deficiencies and operational constraints for upscaling. The study covered 6 states, 166 villages and 1251 farmers across the country. The increase in micro-irrigated area was 800% in Madhya Pradesh, 150% in Orissa and 300% in Punjab during 2006-2008. A change in the land use pattern (from cultivable waste land to horticulture) in States like Madhya Pradesh, Karnataka, Gujarat, Orissa was discernible. Andhra Pradesh, for example, had 75% of the cultivable waste land converted to horticulture crops due to micro-irrigation. In micro-irrigation, average water savings of 30% to 60% and increases in yield from 20% to 50% have been realized. Micro-irrigation has proven to be a boon to all those farmers having groundwater as the lone source of irrigation. Farmers are now able to expand their irrigated areas, grow high value crops (fruits, vineyards, vegetables, flowers, sugarcane, cotton, etc.) and obtain high yields as they can apply water as per the crop demand and with greater precision.

In some states of India, like Andhra Pradesh and Gujarat, the State Government has carried out institutional reforms to operate the CSS by creating autonomous institutions with full transparency through the use of information technology to monitor progress, performance and financial tracking. This has reduced the operational costs as well as built trust among farmers and other stakeholders. The CSS has helped weaker sections of the society by helping them to put their small land under horticulture crops.

The Indian micro-irrigation industry’s current size is estimated at US$ 500 million and is expected to grow by 20% to 30% annually. There are over 150 manufacturers and suppliers of micro-irrigation components both in organized and unorganized sectors. The world’s largest manufacturing company of micro-irrigation products is in India, which shares about 55% of country’s sprinkler and micro-irrigation market. Many States like Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Rajasthan, have allocated significant budgets for expanding the area under micro-irrigation. Successful efforts are in progress to extend micro-irrigation technology in canal command areas.


There has been increasing awareness in adopting water saving irrigation technologies, especially for rice irrigation which is the dominant irrigated crop in Asia. Techniques such as an alternate wetting and drying (AWD) system (Box 3), broad ridges and furrows, use of centre pivots to irrigate rice with less water and raise crop yield are increasing.

**Box 3. A Water Tube to Implement Water Saving using the Alternate Wetting and Drying Irrigation System for Rice**

Traditionally, rice is grown in continuously flooded fields, wherein almost half of the applied water is lost as percolation and seepage. To save water, farmers primarily have to reduce these outflows while maintaining evapo-transpiration requirements to secure a good rice yield. One technology for doing this is alternate wetting and drying (AWD) irrigation. AWD does not require rice fields to be continuously flooded. Farmers re-flood their fields only after a certain number of days have passed following the disappearance of ponded water. With optimal management, this technology reduces the amount of water required by a quarter without reducing yields. We call this safe AWD. The AWD concept, previously called intermittent irrigation, has been studied for more than a decade. Scientists, however, did not come up with recommendations accepted by farmers to implement safe AWD. Some scientists gave recommendations in terms of the number of days of non-flooded soil in between irrigations. Others recommended that irrigation be given when soil water tension in the root zone reached a threshold value of 10 kPa. However, the terms “soil water tension” and “kPa” were completely alien to farmers. Furthermore, farmers did not have suitable equipment to know when the threshold was reached. As a consequence, AWD was not adopted widely by farmers. What farmers need are simple messages tools to help them make decisions on when to irrigate. Scientists at the International Rice Research Institute
(IRRI), found that when field water level recedes to 15 cm below the soil surface, soil water tension in the root zone is always <10 kPa, ensuring good yield.

A practical way to implement safe AWD is to monitor the depth of ponded water using a field water tube. This tube can be made of plastic pipe or bamboo 30–35-cm-long and 15 cm or more in diameter and is perforated on all sides. Farmers can see and monitor the surface of water inside the tube. After transplanting, farmers keep the field submerged for about 2 to 3 weeks to suppress weed growth. The tube is then inserted into the soil leaving 10 cm above the soil surface, and soil is removed down to the bottom of the tube.

Water will flow through the holes into the tube, so that the water level inside the tube is the same as outside. After irrigation, the field water level will gradually subside. When the water level observed in the tube drops to 15 cm below the soil surface, irrigation should be applied to re-flood the field up to 5 cm. This cycle is repeated throughout the season, except from a week before until a week after flowering, when the field should be kept flooded to prevent sterility from occurring. After that, the water level can be allowed to drop again to 15 cm below the surface before re-irrigation.

This technology has been widely validated in farmers’ fields by various national institutes and organizations in the Philippines, Bangladesh, and Vietnam. Everywhere, farmers reported a reduction in water use of 15–30%. This translates into a reduction in pumping cost and fuel consumption, and higher income. The Bangladesh Rice Research Institute reported that AWD increased farmers’ income by US$67–97 per ha. In Vietnam, the technology also resulted in a 15% yield increase. In the Philippines, PhilRice and the National Irrigation Administration have successfully used AWD to improve equity and reduce upstream–downstream conflicts in canal irrigation systems.

This technology has now reached 60,000–70,000 farmers in the Philippines, and tens of thousands in Bangladesh and Vietnam. Realizing its profound impact on farmers, the Bangladesh Department of Agriculture approved AWD for nationwide dissemination. The Philippine Department of Agriculture was working toward an Administrative Order authorizing AWD to be practiced in all irrigation systems nationwide.


Effective on-farm irrigation scheduling is only possible when the conveyance system supplies the irrigation water at the expected time, rate and duration. The selection of an appropriate operation method befitting to the local situation is therefore of importance.

Parallel to on-farm irrigation technology, there have also been advances in agricultural drainage technology. Sub-surface drainage systems using corrugated perforated PVC pipes and automatic drain pipe laying machines have greatly contributed to reclaiming and/or preventing water logging and salinity of irrigated lands on a sustainable basis. Some of the most detailed research, investigations and pilot installations of horizontal subsurface drainage for salinity and water logging control were conducted in the Chambal Command Area in Rajasthan, India (RAJAD 1995).

In many countries, especially in South Asia, there has been exponential growth in groundwater irrigation. Groundwater provides greater control over time and duration of irrigation to farmers leading to higher crop productivity. Rapid growth in deep well pumping technology during the past decades has further spurred the groundwater irrigation expansion in many Asian countries. India, for example, has a very vibrant pump industry which manufactures a wide range of irrigation pumps (centrifugal, submersible, and turbine), which are easily available in the Indian market at affordable prices. Indian farmers can lift water from aquifers as deep as 300 meters or more. India had more than 20 million groundwater wells for irrigation purposes by 2009. This trend has lead to the water levels in aquifers declining at an alarming rate and raises concerns about sustainability of this option for irrigated agriculture. A recent World Bank report (2010) indicated that by 2050, an estimated 60% of India’s
groundwater blocks will be in a critical condition or overexploited. Legal provisions that enable proper restraint of the over-abstraction and community management of groundwater resources are unavoidable in the near future.

**Soft Tools for Operation, Maintenance, Monitoring and Evaluation**

Beside the advances in the hard technologies at the off-farm and on-farm scale, irrigation engineers and managers have been developing soft tools for improved operation, maintenance, monitoring and evaluation of irrigation systems. Canal operation simulation models are acknowledged as optional tools for improving the design and operation of irrigation canal systems. The availability of low cost personal computers has given a large number of canal irrigation managers access to simulation models. These models can be of great help for the comparison of various design alternatives, for the development and tuning of operational strategies and automatic control algorithms and for operation or for training (Goussard, 2000).

Modern tools like FAO’s RAP and MASSCOTE (Renault et.al. 2007), benchmarking of irrigation schemes jointly developed by FAO-IWMI-ICID, internet-based irrigation scheduling, and FAO’s Aqua Crop have been successfully tried in improving performance of irrigation schemes.

Satellite remote sensing and geographic information systems are being successfully used for assessment of irrigation potential, extent of water logging and soil salinity, and assessment of crop productivity. Countries like Australia and Japan are already implementing an ‘Asset/Stock management program’ using modern techniques and materials (Box 4).

**Participatory Irrigation Management as an Effective Soft Option for Better Water Management**

During the past few decades, there have been numerous and significant recommendations by governments and other agencies involved in water basin management with a change in water governance offering the potential to get better results from irrigated agriculture. Participatory irrigation management (PIM) was advocated with water users associations administering the water supply in various countries and regions within. The scope for water savings is apparent from the available statistics in 2009. (Box 5). Another example of Water User Associations is seen in Japan where specific guidelines have been issued and successful management of on-farm irrigation facilities are encouraged (Box 6).

**THE GROWING CHALLENGES**

Water resources, both in terms of quantity and quality, are critically influenced by human activity including agriculture and land use change, construction and management of reservoirs, pollutant emissions and water and wastewater treatment. Water use is linked
primarily to changes in population, food consumption, economy (including water pricing), technology, lifestyle and society’s views about the value of freshwater ecosystems.

**Box 4. Implementation of Stock Management in Japan**

Japan has made huge investments in irrigation infrastructure construction in the past and most of the development of large-scale irrigation and drainage facilities has been completed. Today, most of these infrastructures have exceeded their standard life. However, due to decreasing budgetary allocation, Japan started a new program called “Stock Management Program” in 2007 with the objective of focusing on measures to effectively maintain the function of the various infrastructures and facilities with minimum cost. The stock management focuses on preventive maintenance technologies including modern techniques like sound waves to check for pipe leakages and repairing concrete lining with modern materials like polymers. A semantic of conventional and modern stock management approaches is shown in the following figure.

![Graph showing conventional and modern stock management approaches](image)

*Source: Dr. Yohei Sato, Chairman, Japanese National Committee of ICID (JNC-ICID), Communication to ICID Central Office*

Among the most important drivers of water use are population and economic development, but also changing societal views on the value of water. The latter refers to the priority of domestic and industrial water supply over irrigation water supply and the efficient use of water, including the extended application of water-saving technologies and water pricing. India’s National Water Policy, for instance, assigns first priority for drinking water, followed by irrigation water supply although the States have the freedom to alter the priorities as appropriate. ICID looked critically at some basins in a few countries including India in an exercise titled ‘Country Policy Support Programme’ that examines the impacts of different policies with respect to water use for people, food and the environment. Linking surface and groundwater within each basin and the need to integrate land and water management was

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3 ICID Country Policy Support Programme, 2006 (downloadable from official ICID website www.icid.org)
advocated. Environmental needs would thereby be included in shaping future policy options for basin water and land management.

**Box 5. The Case of the Dharoi Project, Gujarat, India**

In the Dharoi Project in Gujarat State, India, a 26,000 hectare command area has been brought under Participatory Irrigation Management (PIM) with about 130 trained Water User Associations (WUAs).

It is estimated that about 40 million cubic meters (MCM) of water could be saved in a year with proper system management and irrigation management carried out by WUAs. This results in a savings of about 1500 cubic meter of water per hectare. The investment in hardware and software has been in the order of Rs. 2500 per ha. The investment required to create new storage is about Rs. 20 per m³. The 1500 m³ of water saved therefore would correspond to Rs. 30,000 per ha. Thus a minimal investment of Rs. 2500 saves Rs. 30,000. PIM also helped in enhancing water supply to an increased area of about 25%.

A survey of yield increases in sample areas of 1258 ha in three WUAS of Rangpur, Kiyadar and Thalota found that increases in yields of wheat, mustard, cotton, castor, and fodder were 60%, 33%, 23%, 18%, and 33%, respectively. Even if the increase in food crops is considered to be one ton per ha, these gains would correspond to an increase of about 25% in food produced, per unit of water. Translated in terms of quantity, this would be about 1000 m³ per ha, or Rs. 20,000. Thus Rs. 2500 per ha invested results in a savings of Rs. 50,000.

PIM results in higher farmer income, increased employment, increased milk production, and a reduction in migration and have thus it has a multiplier effect.

The Member Planning Commission of India at the Centre, Dr. Kirit Parikh, impressed with the results indicated that Gujarat had given the AMUL model of white revolution to the country and now the Dharoi model can give the blue revolution to the country. 

Source: A personal communication to ICID Central Office seeking statistics on costs and benefits by introducing soft and hard technology - from Mr. V.R. Patel, Former Chairman, Central Water Commission of India and Indian National Committee on Irrigation and Drainage (INCID).

**Box 6. Guidelines for On-farm Irrigation Development and Management in Monsoon Asian Countries**

Assuring the sustainability of irrigation projects requires appropriate management of irrigation facilities with the participation of the water users. In many countries in the Asian monsoon region, however, on-farm irrigation facilities, such as farm ditches, are underdeveloped due in part to financial constraints, compared with the main facilities. Water user organizations (WUOs) of farmers that are responsible for the management of on-farm irrigation facilities are also underdeveloped.

Japan has a long history of developing a form of rice cultivation based on irrigation and drainage facilities with the participation of farmers. By taking advantage of this experience, the Rural Development Bureau, Ministry of Agriculture, Forestry and Fisheries of Japan intends to expand technical cooperation to developing countries in the Asian monsoon region so that they will be able to achieve more efficient water use and sustainable agricultural production.

Given the increasing importance of on-farm irrigation development (OFID) in the future, the bureau compiled the guidebook, “Guidelines for On-farm Irrigation Development and Management in Monsoon Asian Countries”. The guidebook is a compilation of the concepts and procedures such as how to plan, design, construct and manage for OFID and water management in the Asian monsoon region to improve the efficiency of water use and sustainable development in the region. In addition, when planning projects with WUOs, farmer’s wishes can be reflected in these projects and farmer’s understanding can be enhanced for management in the future.

Source: *Guidelines for On farm Irrigation Development and Management in Monsoon Asian Countries* by Rural Development Bureau, Ministry of Agriculture, Forestry and Fisheries, Japan.
even though their number is likely to be small. With increased temporal runoff variability due to climate change, increased water storage behind dams may be beneficial if annual runoff does not decrease significantly. Consideration of environmental flow requirements may lead to modified reservoir operations. In the future, desalination and wastewater reuse are likely to become important sources of water supply in semi-arid and arid regions. Use of poor quality water for irrigation, deficit water application and increasing crop productivity under drought conditions with drought tolerant crops are now widespread. An increase in wastewater treatment and reuse in agriculture will be a necessity, particularly in water stressed basins in Asia, and in arid and semi arid areas.

**IN MONSOON ASIAN COUNTRIES**

The dominant drivers of future irrigation water use are: the extent of irrigated areas, crop types, cropping intensity and irrigation water use efficiency. Most expansion is projected to occur in already water-stressed areas such as southern Asia, northern China, the Near East and northern Africa. The extensive areas being irrigated in Southern Asia largely lie in the Indo Gangetic and Brahmaputra basin plains extending downstream to the Sea. These basins, fed by the Himalayas, are vulnerable due to climate change especially with regard to agricultural water availability for non rainy season crops.

A recent study by the International Centre for Integrated Mountain Development (ICIMOD) brings out a few facts that have great implications for Asia in particular. About 1.5 billion people live within the basins of the rivers of the Greater Himalayas including over 700 million within the Indus and Ganges-Brahmaputra basins, and over 500 million within the Yellow and Yangtze basins. Many more people, almost half of the world’s population, live within countries that depend on economic production sustained by these rivers (e.g., food, energy, industrial production). These populations are growing, and their water demand is growing even faster, due to economic growth. The Himalayan glaciers contain the largest body of ice outside the Polar Regions, providing critical dry-season and long-term water storage. In the case of the Indus, about 45% of river flow is directly from glacier melt (this figure is about 9% for the Ganges and 12% for the Brahmaputra). Flood impacts in the region, the population affected and number of deaths, are higher than in any other region.

Climate change related studies warn the likelihood of a faster temperature increase at high altitudes. In the Greater Himalayan region, models predict rising temperatures and decreasing snow and ice although some of these aspects are subject to further review by independent country studies. According to ICIMOD\(^4\), data since 1960 indicate that glacier retreat is taking place more rapidly in the Himalayas than the global average, and apparently faster than any other major mountain range. Increased precipitation is also predicted in the region, with higher variability and extremes, resulting in greater flood and drought shocks. As a consequence of the loss of glacier storage, overall flows of major rivers are expected to increase in the short run, and then to decrease due to the reduction of snow melt water, in some cases potentially very dramatically.

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\(^4\) ICID Country Policy Support Programme, 2006 (downloadable from official ICID website www.icid.org)
Uncertainties and data gaps notwithstanding, the changing pattern of flows in the rivers of the Greater Himalayas, storages across the rivers (available and planned) are important for future food supplies in the Asian region, especially to address the challenges due to climate and environment.

CONCLUSIONS

Use of appropriate technologies for water storage, conveyance, flow control and regulation, field application, scheduling, drainage of excess water, and maintenance of infrastructure greatly enhances the performance of irrigation schemes. The following key messages or recommendations are proposed for effectively promoting, adopting and deriving benefits from irrigation technologies in the Asian region.

- Development of appropriate and adaptive technologies befitting local needs is required; these have to be readily accessible to farmers and irrigation managers.

- Enhanced investment in on-farm irrigation technologies, especially, micro and sprinkler irrigation which not only reduce irrigation water consumption but also increase crop yields and optimum utilization of other inputs like fertilizers, energy and labour is the foremost need for the future of Asian irrigation.

- Strengthening the State/National Irrigation Extension/Advisory Services for the successful transfer of improved irrigation technologies at the farm level are to be supported. It is crucial to deliver the technologies to millions of small and subsistence farmers.

- Investments in irrigated agriculture have proved to be very cost effective as they guarantee high economic returns in terms of increased water and crop productivity.

- To enhance investment in technology development, promotion, and application outside of public investment, governments could encourage an active participation of manufacturers/suppliers and private organizations.

- There is a continuing necessity of capacity development and training of irrigation managers field staff and farmers to keep abreast of both off-farm and on-farm irrigation technologies.

- For technology adoption on a sustainable basis, improvement in irrigation services through reorganizing and upgrading irrigation agencies is a prerequisite; there will be a need for technological support for the water user associations who are to be engaged in PIM.

- Specific incentives to farmers and reforming other linkages such as markets outside the irrigation sector are important.

- International financing institutions, bilateral and multilateral donor agencies should come forward to provide required funding in up-scaling and adoption of irrigation technologies and practices for using water in the most efficient and effective ways in developing countries.
Increasing private sector involvement in irrigation and drainage infrastructure investment and renewal is crucial, since this can no longer be covered just by the public sector.

Use of wastewater in peri-urban agriculture has become a reality in many Asian countries. The challenge is to promote already available technologies in managing these waters considering food safety, environmental issues, institutional arrangements, and national and regional policies.

Pricing towards cost recovery objectives could contribute to a reduction in water use and help meet at least operation and maintenance costs of irrigation schemes. In due course this may even enable charging a part of the capital cost to the farmers, in order to achieve long term system sustainability.

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## Irrigation and Water Withdrawal in Asian Countries

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<tr>
<th>Country</th>
<th>Arable land (million ha)</th>
<th>Irrigated area (million ha)</th>
<th>% of irrigated area</th>
<th>Drained area (million ha)</th>
<th>Population in agriculture (%)</th>
<th>Water withdrawal for agriculture (%)</th>
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<td>95</td>
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<tr>
<td>Vietnam</td>
<td>6.70</td>
<td>3.00</td>
<td>34</td>
<td>1.00</td>
<td>67</td>
<td>68</td>
</tr>
<tr>
<td><strong>Sub-Total</strong></td>
<td>65.07</td>
<td>16.69</td>
<td>18.5</td>
<td>10.3</td>
<td>53.8</td>
<td>84.5</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Kazakhstan</td>
<td>21.54</td>
<td>2.12</td>
<td>16</td>
<td>0.53</td>
<td>19</td>
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<tr>
<td>Kyrgyzstan</td>
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<td>1.07</td>
<td>74</td>
<td>0.15</td>
<td>25</td>
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<tr>
<td>Tajikistan</td>
<td>0.93</td>
<td>0.72</td>
<td>68</td>
<td>0.32</td>
<td>33</td>
<td>92</td>
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<tr>
<td>Turkmenistan</td>
<td>1.85</td>
<td>1.80</td>
<td>79</td>
<td>1.03</td>
<td>33</td>
<td>98</td>
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<tr>
<td>Uzbekistan</td>
<td>4.48</td>
<td>4.28</td>
<td>85</td>
<td>2.82</td>
<td>27</td>
<td>93</td>
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<tr>
<td><strong>Sub-Total</strong></td>
<td>30.15</td>
<td>9.99</td>
<td>64.4</td>
<td>4.85</td>
<td>27.4</td>
<td>91.8</td>
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<td><strong>West Asia</strong></td>
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<tr>
<td>Georgia</td>
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<td>0.47</td>
<td>44</td>
<td>0.15</td>
<td>19</td>
<td>59</td>
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<td>Iran</td>
<td>15.02</td>
<td>8.70</td>
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<td>0.19</td>
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<td>Iraq</td>
<td>5.75</td>
<td>3.52</td>
<td>23</td>
<td>1.54</td>
<td>10</td>
<td>92</td>
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<td>Israel</td>
<td>0.34</td>
<td>0.19</td>
<td>24</td>
<td>0.10</td>
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<td>62</td>
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<td>Jordan</td>
<td>0.30</td>
<td>0.08</td>
<td>11</td>
<td>0.01</td>
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<td>75</td>
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<tr>
<td>Saudi Arabia</td>
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<td>1.62</td>
<td>81</td>
<td>0.04</td>
<td>9</td>
<td>89</td>
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<tr>
<td>Syria</td>
<td>4.59</td>
<td>1.33</td>
<td>76</td>
<td>0.27</td>
<td>27</td>
<td>95</td>
</tr>
<tr>
<td>Yemen</td>
<td>1.54</td>
<td>0.55</td>
<td>34</td>
<td>1.50</td>
<td>50</td>
<td>95</td>
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<tr>
<td><strong>Sub-Total</strong></td>
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<td>16.46</td>
<td>40.25</td>
<td>3.65</td>
<td>21.7</td>
<td>82.25</td>
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<tr>
<td><strong>Oceania</strong></td>
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<tr>
<td>Australia</td>
<td>48.30</td>
<td>2.55</td>
<td>5</td>
<td>2.17</td>
<td>NA</td>
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<td>New Zealand</td>
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<td>11</td>
<td>NA</td>
<td>NA</td>
<td>42</td>
</tr>
<tr>
<td><strong>Sub-Total</strong></td>
<td>49.80</td>
<td>2.84</td>
<td>8</td>
<td>2.17</td>
<td>-</td>
<td>58.5</td>
</tr>
<tr>
<td><strong>Total for Asia &amp; Oceania</strong></td>
<td>762.53</td>
<td>198.44</td>
<td>35.4</td>
<td>60.52</td>
<td>39.1</td>
<td>86.3</td>
</tr>
</tbody>
</table>

6. AN OVERVIEW OF INDIA’S WATER MANAGEMENT SCENARIO FOR ENSURING FOOD SECURITY

M. Gopalakrishnan*

ABSTRACT

A rising population with an increasing average caloric intake means that India will need to double its crop production over the next 50 years in order to be self-sustaining in food production. Agriculture contributes over 20% to the Indian gross domestic product, and an estimated 65% of the population depends directly or indirectly on the farming sector for their livelihoods. About 40% of India’s cultivated land is irrigated and agriculture is heavily dependent on the monsoon rainfall and this already variable precipitation will be aggravated by climate change. Agriculture is responsible for over 80% of total water withdrawals in the country and is vulnerable to increasing water scarcity due to rising demands from other sectors, overuse of groundwater, irrigation inefficiencies and aging infrastructure. The development of reliable sources of water for irrigated agriculture, land and water management to maximize crop production, the diminishing average farm size and the large population of undernourished people are serious challenges that India must overcome if food security is to be attained.

INTRODUCTION

The pressure on India’s natural resources, land and water is becoming more and more severe with the necessity to meet the basic needs of the ever-increasing population. The diverse nature and distribution of resources within the country, due to varying demographic, climatic, meteorological, social and cultural factors make dealing with the problems of food,

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water and livelihood security very complex. India has roughly 17% of the world’s population concentrated on 2.45% of the land area and is endowed with just above 4% of the world’s water resources. The population is 1.15 billion, second only to China, and 70% of this population lives in rural areas. It is anticipated that the population will rise to 1.6 to 1.8 billion by 2050.

India demonstrated its inherent resilience in 2008 when it withstood the global food crisis and the subsequent economic recession coupled with the steep rise in the price of oil. Despite impressive gains in economic investment and output however, India faces pressing problems such as significant overpopulation, environmental degradation, extensive poverty, and ethnic and religious strife. According to the FAO (FAO, 2011a) 21% or 238 million people are undernourished in India. A look into past, present as well as future food needs of India and their connection to water as one of the key and essential inputs for food production is the aim of this chapter.

Three major aspects1 of dealing with India's preparedness in the coming decades to assure food security are:

1. Food availability: Making available the food required to feed the increasing population requires estimating future food demands and assuring production with irrigated agriculture. This would include sustainable land and water management which assume great importance as demands from other sectors increase and resources become increasingly scarce.

2. Reliable water supply: Sustaining food self sufficiency in an environment where water demand and supply varies due to the vagaries of monsoons, rainfall patterns and climate change is a great challenge. Special interventions and adequate water storage to reduce the risk of an uncertain water supply is critical to food security in India.

3. Food affordability: In a country with a sizeable poor population, affordability of food also plays a role in ensuring food security. The Indian government provides substantial social measures to try and ensure food is affordable to all.

FOOD AVAILABILITY

Background

Farming has been practiced for centuries in India and it has an enviable asset of land suitable for agriculture and water from rainfall that averages 1180 mm year. Human settlements

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1 The author of the paper has presented three lectures at McGill University's Global Food Security Conferences since its inception in 2008. The three aspects listed formed part of the main lecture in 2010 although earlier lectures given in 2008 and 2009 also contain references to this material.

The PowerPoint presentations and webcasts are available at http://www.mcgill.ca/globalfoodsecurity/ under M. Gopalakrishnan and may help serve as simultaneous reference material.
along the vast river systems of the Indian subcontinent date back several millenniums. In Tamilnadu, a stone masonry barrage was built 1900 years ago across the River Cauvery by the then ruling Chola kings. This structure, an engineering marvel that serves even today, enabled the entire Cauvery delta, the grain bowl of the south, to flourish. For centuries the land fed its population with its natural resources. With India’s partition in 1947, the historically well-developed irrigated areas of over 50% of the Indian continent, lying mostly in the mid- and tail parts of the Indus Basin, became part of Pakistan. An immediate problem on achieving independence for India was therefore food production. The new Republic of India made development of water resources and irrigation facilities to ensure food security a priority. The sixties saw the country facing famine and a goal of self sufficiency was born out of this acute grain shortage for internal consumption. Special attention was paid to the development of large scale storage projects and irrigation facilities to enable a successful Green Revolution in India.

Successive five year plans assigned a major investment to water, power and agriculture and by the 1980s one could see its visible impacts, especially in food self sufficiency. The revolutionary practices in the agricultural sector made it possible to become a food exporting nation by the turn of the millennium which enabled a large section of the population to diversify their attention to other sectors of nation building.

**Agricultural Production**

Agriculture is the mainstay of the Indian economy. Agriculture and allied sectors contribute nearly 22% of the gross domestic product (GDP) of India. There are approximately 120 million farms in India with an average size of 1.3 ha and 65-70 % of the population is dependent on agriculture for their livelihood. There are 183.4 million ha of cultivated land and about 80% of it is used to grow India's main foods including grains (rice, wheat, millet and sorghum) and pulses (beans, chickpeas, and pigeon peas). India has more cattle and buffalo than any other country. These animals are not butchered for meat, but are important to the economy for their milk.

Nearly 60% of the cultivated area in India grows rainfed crops including nearly half the cereals, 90% of the pulses, and 80% of the horticulture and overall agricultural output depends largely on the Indian monsoon. Annual rainfall occurs during approximately 100 hours during the monsoon which ranges from 3 to 4 months in different parts of the country. The monsoon rains come in short spells (often as storms), and can result in severe floods and colossal losses of life, crops and livelihoods. Rainfall varies widely across India from about 100 mm annual precipitation in western areas to as high as 11 000 mm in the northeastern parts.

Food grain production, a meager 51 million tonnes (MT) at the time of India’s partition in 1947, increased over four fold to 232 MT in 2003, which subsequently declined to about 212 MT in 2004 due to, among other factors, a lack of investment in the preceding decade in water resource management. It has been estimated that as much as
52 to 60% of the rise in food grain production was due solely to irrigated agriculture. Current average food consumption is 2400 calories per person day but the prevalence of poverty is still high, and improving and expanding irrigation is considered to be key to farmer prosperity.

**Potential Effects of Climate Change**

The already uneven spatial and temporal distribution of rainfall will be aggravated by climate change and rising temperatures and are likely to cause reduced grain yields, particularly in rainfed areas (IPCC, 2007). In addition, Himalayan glaciers, unique reservoirs that support perennial rivers such as the Indus, Ganga and Brahmaputra which are the lifeline of millions of people in India, are shrinking. The current trends of glacial melt suggests that although in the immediate future increased snowmelt could increase river flows, the Ganga, Indus, Brahmaputra and other rivers that criss-cross the northern Indian plain could likely become seasonal rivers in the longer term. This is a consequence of climate change with significant potential effects on regional food security (IPCC, 2007).

**Food Requirements**

The “Report of the National Commission for Integrated Water Resources Development” released in 1999, by the Ministry of Water Resources, India², estimated food demand in 2025 and 2050 and developed actions with respect to agricultural production and irrigation necessary to meet this demand (Table 1). The necessity to double India's present level of food production to 500 million tonnes in order to achieve self sufficiency in food production is obvious from this document. There is recognition of the need for placing agriculture on a growth path of around 4% or about half of what the country plans for the overall GDP growth rate.

The increased food demand is not only a result of a rising population but is also a function of a large proportion of that population moving toward a higher calorie, middle-class diet.

**WATER RESOURCES AND MANAGEMENT**

India has 13 large river basin systems including 7 lumped systems that drain to the east and west coasts and 2 minor inland systems (the Rajasthan and North Eastern river basins). The vast coastal deltaic belts in the east as well as the alluvial plains in the Gangetic and Brahmaputra have supported cereals and a variety of other crops, fruits and vegetables from time immemorial.

Overall water availability including precipitation in all forms as well as flows from rivers across international boundaries (Mean Annual Flows) can be seen in Table 2. In India

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utilizable water is estimated based on the amount of water that can be withdrawn from its place of natural occurrence (like rivers with respect to surface water and groundwater aquifers with respect to subsurface water). Limitations to the amount of water that can be withdrawn include physiographic, environmental, legal and technical.

### Table 1: Projection of food requirements and cultivable areas (including irrigated)

<table>
<thead>
<tr>
<th>Details</th>
<th>(2003-2004)</th>
<th>2025</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Food grain Demand (million tonnes)</td>
<td>Circa 220-230</td>
<td>308</td>
<td>320</td>
</tr>
<tr>
<td>Net Sown Area* (million ha)</td>
<td>143</td>
<td>144</td>
<td>144</td>
</tr>
<tr>
<td>Gross Cultivated Area^ (million ha)</td>
<td>190</td>
<td>202</td>
<td>204</td>
</tr>
<tr>
<td>Gross Irrigated Area (million ha)</td>
<td>75</td>
<td>91</td>
<td>98</td>
</tr>
<tr>
<td>Gross Irrigated Area for Food</td>
<td></td>
<td>70% of gross irrigated area for food crops</td>
<td></td>
</tr>
<tr>
<td>Rainfed Area (million ha)</td>
<td>115</td>
<td>111</td>
<td>106</td>
</tr>
<tr>
<td>Rainfed Area, Food</td>
<td></td>
<td>66% of rainfed area for food crops</td>
<td></td>
</tr>
<tr>
<td>Irrigated Food Yield (t/ha)</td>
<td>2.75</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Rainfed Food Yield (t/ha)</td>
<td>1.25</td>
<td>1.25</td>
<td>1.25</td>
</tr>
<tr>
<td>Food Production (in million tonnes)</td>
<td>212-232</td>
<td>307</td>
<td>322</td>
</tr>
</tbody>
</table>

*Total area sown to crops. ^ Total area sown once and/or more than once in a particular year. (i.e. the area is counted as many times as there are sowings)

### Table 2: Overall water availability in India

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Description</th>
<th>Annual Quantum in billion m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total Precipitation in all forms (rain, snow etc)</td>
<td>4 000</td>
</tr>
<tr>
<td>2</td>
<td>Average Annual River flows (Surface Water)</td>
<td>609</td>
</tr>
<tr>
<td>3</td>
<td>Utilizable Water Resources (Surface Water)</td>
<td>690</td>
</tr>
<tr>
<td>4</td>
<td>Replenishable Groundwater</td>
<td>432</td>
</tr>
<tr>
<td>5</td>
<td>Total Annual utilisable water</td>
<td>1122</td>
</tr>
<tr>
<td>6</td>
<td>Present Level of Utilization</td>
<td>605</td>
</tr>
<tr>
<td>7</td>
<td>Projected Water Requirement in 2050</td>
<td>Circa 1440</td>
</tr>
</tbody>
</table>

Irrigation withdrawals account for over 87% of total water withdrawals (Table 3). Even a 20% improvement in surface irrigation of the large scale surface irrigation systems would save only 22 million m³, a small proportion of total surface irrigation withdrawals and inadequate for the expanded water needs for future food production.
Table 3: Water withdrawals and returns for different sectors

<table>
<thead>
<tr>
<th>Details of Usage</th>
<th>Withdrawals</th>
<th>Return Flows as adjudged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Irrigation</td>
<td>318</td>
<td>16</td>
</tr>
<tr>
<td>Groundwater Irrigation</td>
<td>206</td>
<td>141</td>
</tr>
<tr>
<td>Domestic Use</td>
<td>30</td>
<td>21</td>
</tr>
<tr>
<td>Industrial Use</td>
<td>39</td>
<td>18</td>
</tr>
<tr>
<td>Lake Evaporation</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>629</td>
<td>196</td>
</tr>
<tr>
<td>Total Consumption</td>
<td>433</td>
<td></td>
</tr>
</tbody>
</table>

Irrigation Development: Past and Present

Irrigation to produce food grains has existed in India since prehistoric times. Following major famines at the end of the 19th century, major irrigation canals were built, and in 1900 the Indian peninsula (including Bangladesh and Pakistan) had some 13 million ha under irrigation (FAO, 2011b). In 1947, India had about 22 million ha under irrigation. High priority has been given to irrigation with nearly 10% of all planned outlays since 1950 being invested in irrigated agriculture. This has resulted in 0.6-0.7 million ha of new irrigated schemes being developed every year on average. Multipurpose large and medium dams in various river basins were built to create water storage and realize hydro power where feasible, and canals and smaller diversion structures, barrages and small tanks were established throughout the country to combat drought during the growing season. Approximately 75 million ha are currently irrigated in India in major (>10 000 ha), medium (2 000-10 000 ha) and minor (<2 000 ha) irrigation schemes. Minor irrigation projects generally have both surface water and groundwater as sources, while major and medium projects exploit surface water resources. Fresh surface and groundwater water withdrawals for irrigation are 83% of total withdrawals and may decline to about 70% with measures to enhance efficiency in water use. The broad assessment of the area that can be ultimately brought under irrigation, both by surface and groundwater, made by the various States in the Union put the ultimate irrigation potential of the country at 139 million ha.

Surface Irrigation

The outlay on surface irrigation, which used to account for the bulk of public investment in agriculture, was concentrated on projects that have taken an unconscionably long time to complete. In many cases, the project costs shot up. Subsequent outlays to ensure proper completion have not resulted in any significant additions to irrigated area. Inadequate allocations for system operation and maintenance and poor cost recovery due to lack of willingness to pay by the beneficiaries are a problem in almost all the large scale irrigation systems.
Groundwater Irrigation

Nearly 60% of Indian irrigation is attributable to groundwater although a precise determination of groundwater contribution to food security is difficult because of the links between ground and surface waters. In many cases, conjunctive use has been a tradition for hundreds of years. For example, many surface water systems and unlined canals recharge groundwater.

Overexploitation of groundwater is a serious problem in some areas and out of 5200 blocks in the country, over-abstraction, beyond natural annual recharge is occurring in about 250 blocks and this number is rising steadily. The Central Groundwater Board (CGWB) observations on “decadal trends” (over a period of ten years) indicate that groundwater depletions exceed a rate of 4 m and more in the dark areas of Figure 1.

Farmer investment has concentrated on groundwater exploitation in recent times, thanks to the advancement of technology, the declining cost of pumps and government energy subsidies. This has resulted in an increased number of wells, and abstraction from deeper depths by installing more powerful pumps and as a consequence wells get deeper, water tables fall, and water becomes scarcer. As pumping costs increase with water depth only better-off farmers have some chance of maintaining themselves in operation and such competition induces a new social imbalance with poor farmers losing the battle. In cases where they raise loans to remain in the game, they find that a stage comes when they are unable to pay back the loan and as seen in a few cases, even resort to the extreme step of committing suicide.

Figure 1. Decadal Trend in Groundwater Depletion
WATER MANAGEMENT FOR GLOBAL FOOD SECURITY

The unsustainable groundwater usage and/or expansion needs discouragement and the legal remedies are still limited in India. Areas converting from surface to groundwater usage due essentially to poor irrigation services rendered, need urgent attention and reversal to surface irrigation. With the new thrust for Water Users Association formation and Participatory Irrigation Management coupled with the formation of Water Resources Regulatory Authorities in nearly 16 States of the Union, better surface water irrigation management looks feasible.

Rainwater Harvesting

The impetus given to rainwater harvesting for supplemental irrigation in recent times has shown mixed results. The potential to enhance the overall food productivity from rainfed lands will demand new models in governance and are as yet in experimental stages. Scaling up would be a big challenge as the costs of rainwater harvesting are very high (2030 Water Resources Group, 2009).

Water Storage

The live storage created annually with dams and barrages for major, medium and minor irrigation schemes (Table 4) plays a significant role in supporting the irrigation potential.

<table>
<thead>
<tr>
<th>Table 4: Live storage availability (10⁶ m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major Irrigation Projects</td>
</tr>
<tr>
<td>214.52</td>
</tr>
</tbody>
</table>

Given the variations in the spatial and temporal distribution of rainfall, geography and land use, storage dams are a necessity for conservation of excess monsoon flows to meet the rising demand for water. With the rapidly growing population, a growing middle class, increased urbanization and industrialization, more and more water shortages are being felt across the country and in some cases severely. Water storage capacity varies widely throughout India and much of the country has less than 100 days of water storage (Figure 2). In Brahmaputra (darkest colour on map) there are only 2 to 3 days of storage.

A total of about 176 billion m³ of ‘built up storage’ has been created. Another 76 billion m³ of storage capacity will be available from projects under construction and there is a 3 billion m³ capacity in small tanks making a future total storage capacity of 256 billion m³. There is yet another 108 billion m³ of identified capacity under consideration.
Future storage could possibly be increased in the Himalayan river basins but as these are internationally shared basins, agreements for shared water usage for the optimal benefit of the region are necessary. This is an urgent water agenda and will require international cooperation in the region.

**Future Water Needs**

The projected water needs estimated by the Government of India in 1999 to ensure doubling of food production by 2050 are seen in Table 5.

The National Water Policy (2002)\(^3\) puts an emphasis on Integrated Water Resources Development and Management as one of the imperatives for the country’s welfare; the policy to harness available water and land should keep in view the future food security and environmental integrity. Both land for agriculture and irrigation water for intensive agriculture will become constraining factors to meet the projected needs of anticipated increases in population, and prudent, ecological and sustainable development and management of available resources will play a primary role. This is a challenge for a developing country with a sizeable population of poor people.

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WATER MANAGEMENT FOR GLOBAL FOOD SECURITY

MEETING FUTURE FOOD AND WATER REQUIREMENTS

Addressing the future food gap in India will be heavily dependent on raising crop yields, increasing the irrigated area and intensifying irrigated agriculture.

Interbasin Transfers

Interbasin transfer for the purpose of maximizing overall water use to the advantage of food security and human welfare is being looked into. The overall program is composed of several water transfer links in the Indian peninsula as well as the northern Himalayas. Long distance water transfer from surplus basins such as the Brahmaputra, Mahanadi and Godavari to deficit basins like Krishna, Pennar, Cauvery and Rajasthan will be a boon to attain the requirements of food needs internally by 2050. The additional water supplied from water rich basins to a few closed basins will provide opportunities to increase the irrigation intensities and allow India to enhance its capacity for food production by creating about an additional 35 million ha of irrigated agriculture. These are of course ‘long term action plans’ that require careful multisectoral study to ensure protection of all ecological and environmental interests while ensuring sustainable development for the country’s future essential food security.

Irrigation

Improved water governance and use of energy is necessary to eliminate misuse and overuse of water resources for surface and groundwater irrigation. Better management of large and medium irrigation schemes is currently being addressed through participatory management of irrigated systems such as the creation of Water User Associations. This will result in more equitable and efficient use of water. In addition, improved efficiency of water, such as increased drip and sprinkler irrigation will also reduce agricultural water use.

<table>
<thead>
<tr>
<th>Table 5: Water Requirements (km³ per year)⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sector</td>
</tr>
<tr>
<td>Irrigation</td>
</tr>
<tr>
<td>Domestic</td>
</tr>
<tr>
<td>Industry</td>
</tr>
<tr>
<td>Energy</td>
</tr>
<tr>
<td>Others</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

Land and Crop Management

Improving land management to increase crop productivity includes no-till farming and improved drainage, and optimizing fertilizer use. Utilization of high quality germplasm, promoting agricultural crops that best fit the agroclimatic zones, using integrated pest management as well as pest resistant and drought tolerant varieties to increase crop yields are supported by ongoing research of numerous scientific and technological institutions. Agricultural extension programs to farmers and mass communication in local languages yield good results.

THE CHALLENGES AHEAD

Risk and Uncertainties in the Widespread Use of Deep Wells in Agriculture

Groundwater exploitation and utilization have made a substantial contribution to the creation of country’s overall food basket over the last several decades. However, the subsidy for the use of energy for agriculture and the lack of sufficient regulations on abstractions of groundwater have resulted in overexploitation in several areas with negative environmental consequences. Gradual changes in governance with the participation of farmers and water user associations are likely to yield improved management, cost recovery for the operation and maintenance and better discipline in asset management.

Climate Change and Erratic Monsoons

Adapting to the risks and uncertainties of increased frequency of droughts and floods associated with climate change with regards to water availability and food is an ongoing concern of the Government of India. With a successful monsoon, record grain production is possible as was the case in 2010. However, the stability of food security in the years ahead needs several essential preparations and manifold actions on different fronts including supplemental irrigation during dry spells, a timely supply of other inputs like fertilizers and ensuring agricultural credit.

Small Farm Size

The mix of large, medium and small scale projects in irrigated agriculture in India, naturally involves numerous stakeholders. Although family farms worked in earlier times, farm holdings are becoming progressively smaller through inheritance, and further family farm divisions pose a challenge in planning profitable solutions using irrigation and cropping. Bringing the benefits of food production to millions of small holder farmers is an extremely complex situation that is unique to this part of the world. Agriculture provides a livelihood for about 65% of the population and any blueprint for ensuring the sustainability of India’s food security and overall production is obliged to keep this factor and its important political
implications in mind. Profarm policies (support for tank and tubewell irrigation, energy subsidies) and associated activities aimed to protect the interests of the small scale holders and rural labour engaged in farming have not been well understood and supported by many hailing from different settings where profitable agriculture is a practice handled by large scale farmers as a commercial venture. They did however, have a major positive impact on food production.

**Securing Food for the Underprivileged**

One of the vexing concerns for India is its status with respect to securing food for the underprivileged. While some assessments describe ‘India is Shining’ because of (i) its status as the 4th largest global economy, (ii) an enviable growth rate of GDP (around 8-10% during the last three years) and (iii) an alert and vigilant society, a younger generation with higher aspirations, a vibrant media and self sufficiency in food, there is another side of the coin that is frustrating. And that is the starving India, the country that has one of the highest numbers of undernourished people (220 million), and is home to nearly 27% of the world’s malnourished. In addition, 43% of children under 5 years are underweight, the highest in the world. This makes the nation ponder its actions on how to respond to these undesirable facts.

India was more successful in reducing poverty in the pre-liberalization era when the government had fewer resources to invest, than it has been in the high GDP-growth phase since 1990. The rapid engines of growth for the Indian economy like the service and industrial sectors haven’t been revving enough in the rural hinterland, where agriculture is the mainstay. Government interventions like the National Rural Employment Guarantee Scheme (NREGA) or piecemeal efforts by NGOs have not been able to redistribute wealth to the rural poor to allow them to benefit from India’s great ‘economic’ growth. This makes it appear that adequate nutrition and health for all is still a long way off. The problem of hunger goes beyond poverty, however and the causes aren’t necessarily attributable to unavailability of grain as one sees rotting crops due to lack of adequate protection, insufficient quality silos, poorly performing distribution systems, lack of dedicated and timely action at various administrative levels, etc. Thus we waste some of the grain produced rather than assuring its delivery to the poor and hungry.

Some success has been achieved in the Indian State of Tamilnadu\(^5\) where technological interventions, innovative and fool-proof food delivery mechanisms have helped the poor. Each family, whether below the poverty line or not, is given a monthly entitlement of 20 kg of rice at about US 0.25 cents/kg. Effective targeting of Below Poverty Line (BPL) families, an administratively difficult task, is squarely addressed and the State is now deservedly held up as a model for a comprehensive food security system. To replicate and upscale such efforts is a challenge of the future.

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CONCLUSIONS

To feed an anticipated Indian population in 2050 of 1.6 - 1.8 billion while at the same time ensuring desirable nutritional standards, food grain production in the order of 450-500 million tonnes per annum is absolutely necessary. This demands the realization of the ultimate irrigation potential of the country. The steps to be taken to increase the existing irrigation coverage will be to enhance production by intensive irrigation and to get more from the developed land and water. An additional amount of water supplied externally from water rich basins to a few closed basins will provide opportunities to increase the irrigation intensities. About 140 million hectares comprising 76 million hectares from surface water and 64 million hectares from groundwater can then supplement the present levels of irrigation. Is it not that water through irrigation assuring food security is an admirable tool for peace, forever?

REFERENCES


7. CLIMATE CHANGE AND CANADIAN AGRICULTURE

Sam Gameda* and Budong Qian**

ABSTRACT

Canada is the world’s fourth largest exporter of agricultural and food products and agriculture is an important component of Canada’s economy. Understanding the implications of climate change on Canadian agriculture therefore has national and international implications for food security. With much of Canada’s agriculture concentrated in the Prairies, the length of the growing season, the number of growing degree days, the amount of heat available during the growing season and the amount of moisture available for crop growth and maturity were assessed for the Prairies using data for baseline and future periods. Projected values for these agroclimatic indices suggest unchanged or broadly favourable conditions for crop production under climate change, particularly if a projected moderate increase in moisture deficits is managed well. When viewed from the perspective of exceeding critical temperature and moisture thresholds, however, the potential for substantially increased risk emerges. The climatic variability accompanying climate change would thus be increasingly important in Canadian agriculture.

INTRODUCTION

Canada is the second largest country on earth, yet only 7% of its land mass is suited for agriculture. Agriculture is an important component of Canada’s economy, contributing to 8% of GDP and 13% of the labour force (AAFC, 2007). Canada is also the fourth

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** Agriculture and Agri-Food Canada (AAFC), Ottawa, Canada
largest exporter and fifth largest importer of agricultural and food products globally (AAFC, 2007).

The effects of climate change on Canadian agriculture would thus have a tremendous impact on both national and global agricultural supplies and associated food security. It is therefore important to quantify the potential impact of climate change on agricultural production in Canada.

The Canadian Prairies constitute the largest tract of agricultural land in Canada, contributing to 80-85% of its total agricultural production. The climatic regime consists of a short growing season with semi-arid moisture conditions and shifts in this regime would have substantial impact on crop production. This chapter focuses on potential changes in agroclimatic conditions for field-crop production in the Canadian Prairies as an indicator of the impact of climate change on Canadian agriculture. In particular, it explores climatic conditions that might impact growing season conditions and changes in moisture availability that would result from projected climate change. Evaluation of potential impacts on agriculture in Eastern Canada has been reported previously (Gameda et al. 2007).

**METHODS USED TO ASSESS CLIMATE CHANGE EFFECTS**

There are several determinants that impact field crop production in Canada: i) growing season conditions delimited by Canada’s winter; ii) the amount of heat available during the growing season; and iii) the amount of moisture available for crop growth and maturity. These were assessed through determinations of growing season temperature and precipitation trends for current and future climates.

Daily values of observed maximum and minimum temperatures and precipitation amounts for the baseline period (1961-90) were obtained from the Agriculture and Agri-Food Canada (AAFC) climate data archive for climate stations across Canada’s agricultural region. Climate station data were then interpolated to a 0.5° grid across the agricultural region. Future climate scenarios for 2040-69 were obtained from the Canadian CGCM3 global climate model (GCM) for the A1B emissions scenario. CGCM3 is the third generation of the Canadian coupled GCM developed at the Canadian Centre for Climate Modeling and Analysis (CCCma) (Kim et al. 2002, 2003). The A1B emissions scenario (Nakicenovic and Swart, 2000) reflects a high growth, globally integrated economic system, and was chosen for illustrative purposes. Daily data from the GCM were downscaled to the same 0.5° grid indicated above using the AAFC-WG stochastic weather generator. The efficacy of AAFC-WG in representing current climatic characteristics and developing climate change scenarios has been extensively explored (Qian et al. 2004, 2005, 2008, 2010a) Uncertainties associated with greenhouse gas emission scenarios, climate modeling and downscaling can be very large, and associated agroclimatic conditions are likely be substantially divergent from projections described herein.

The climatic determinants affecting crop production are best evaluated through the use and assessment of agroclimatic indices. The agroclimatic indices chosen for such assessments are:
i) growing season length (GSL), which provides a measure of the period where temperatures are above threshold values for crops of interest; ii) effective growing degree days (EGDD) and crop heat units (CHU), which are measures of the amount of heat available for cool-season and warm-season crops, respectively; and iii) water or moisture deficit (WD), a measure of the difference between precipitation (P) and potential evapotranspiration (PE). EGDD, CHU and WD are based on daily values accumulated over the growing season. Cool season crops such as wheat and barley grow optimally between minimum and maximum threshold temperatures of 5° C and 30°C, respectively. The optimal range for warm season crops such as corn and soybeans is 10 - 35° C. The growing season starts when spring temperatures have steadily exceeded minimum temperature thresholds for each crop type. The growing season ends for cool season crops when temperatures exceed 30° C or on August 31 and for warm season crops when fall temperatures drop below 10° C. EGDD and CHU are calculated based on accumulated temperature exceedance of threshold values over the growing season. Detailed descriptions of the above indices are given in Qian et al. (2010b).

EFFECTS OF CLIMATE CHANGE ON FIELD CROP PRODUCTION IN THE CANADIAN PRAIRIES

Growing Season Length

The growing season length for 1961-1990 ranges between 119 – 156 days for cool season crops and 131 – 171 days for warm season crops in the Canadian Prairies. These ranges indicate a small difference of approximately 12 – 15 days, in the length of the growing season available for cool and warm season crops. During the 2040-69 period, GSL is projected to be between 106 – 160 days for cool season crops, indicating that little change in GSL is expected, with even a 13 day decline on the lower end, for small grain cereals such as wheat and barley. Future values for warm season crops range between 149 – 195 days, a significant increase of 18-24 days in growing season length for crops such as corn and soybeans. This suggests increased suitability in the Canadian Prairies for warm season crops if sufficient heat units and moisture are available.

Effective Growing Degree Days

Effective Growing Degree Days, or the amount of heat units available for the cool season small grain cereals, ranges between 948 – 1390 for the baseline period and is projected to increase to 1167 – 1507 for the 2040-69 period, a marginal increase of between 117 – 219 units.

Crop Heat Units

Crop heat units for warm season crops such as corn and soybeans were between 1694 – 2851 for the baseline period. These values are on the cool side for warm season crops and
indicate why small grain cereals, with wheat being the most important crop within this mix, are currently the dominant crops in the Canadian Prairies. Projected values of CHU for the 2040-69 period are between 2349 – 3606, a substantial increase of 655 – 755 units. This, coupled with the projected increase in GSL for warm season crops, suggests the possibility for a substantial shift to the production of warm season crops, particularly in the southern Prairies, if moisture conditions are not limiting. Changes in crop heat units between baseline and future climate are shown in Figure 1.

**Water Deficit**

Growing season moisture conditions for crop production can effectively be represented by the difference between precipitation (P) and potential evapotranspiration (PE) accumulated over the growing season to represent moisture deficits over the crop growth cycle. Determinations for cool season crops indicate that, for the baseline period, the WD was between 109 – 394 mm. Although the lower range represents a tolerable level of moisture deficit for crops and thus unlikely to lead to notable changes in production, the higher one corresponds with severe moisture deficits that would result in significant yield losses or even crop failures. These values further confirm the semi-arid characteristic of the Prairies, and attest to the risk associated with crop production in the region. WD under climate change is projected to range between 62 – 376 mm, constituting only marginal improvements in moisture deficits in the Prairies.

**Figure 1.** Crop heat units (CHU) for warm season crops for baseline (upper) and future (lower) climate assessment periods
WD values for warm season crops over the baseline period range between 77 – 478 mm, representing a greater deficit, in the order of 84 mm, than that expected for cool season crops in the drier regions of the Prairies. WD under climate change are expected to range between 51 – 575 mm, indicating that, although the cooler, northern reaches of the Prairies are projected to experience a reduction in moisture deficits, the drier southern region will experience an additional 97 mm of moisture stress. Changes in water deficits for warm season crops between baseline and future climate are shown in Figure 2.

**Figure 2.** Water deficits for warm season crops for baseline (upper) and future (lower) climate assessment periods

Considering the combined effect of all three types of indices, indications are that cool season small grain cereals will not experience substantial changes in production under climate change. Warm season crops, on the other hand, have the potential for increased introduction and expansion in the region, but with increased risks to crop failures or losses due to projected increases in moisture stress.

These findings suggest that projected climate change may not be harmful to Canadian agriculture, and may even be beneficial for the increased production of warm season crops, particularly if the projected increases in moisture deficits are successfully managed. The assessment of 30-year normals or means does, however, have some limitations. Although it provides information about average climatic conditions likely in a future climate, it does not give any information about changes in variability and in the occurrence of extreme climatic events resulting from climate change.
EFFECT OF CLIMATIC EXTREMES ON CROP PRODUCTION

Threshold Temperatures

One way to assess potential disruptions to crop production would be to determine the frequency of exceeding critical threshold temperature and moisture deficit values for major crops. As indicated earlier, upper thresholds for cool and warm season crops are 30 and 35°C, respectively. For the baseline period, the Canadian Prairies experienced temperatures exceeding 30°C for just over seven days during the growing season. Under climate change it is projected that there will be 23 days with temperatures above 30°C during the growing season. These projections indicate that small grain cereals will almost certainly experience temperatures exceeding their threshold values at critical growth stages.

The higher value of 35°C is rarely exceeded in the Canadian Prairies and occurs 0.5 days per growing season for the baseline period. This is expected to increase to 4.4 days per season for 2040-69. In the warmer brown chernozemic soil zone of southern Alberta and Saskatchewan, this temperature occurs 0.8 days per growing season for the baseline period, but is projected to increase to nearly a week (6.5 days) for the 2040-69 period. This indicates that crops could potentially be harmed, particularly if the temperature extreme coincides with a critical growth period.

Moisture Deficits

The Canadian Prairies are classified as a semi-arid region, and often experience substantial moisture deficits. Assessment of the probability of exceeding critical moisture deficit values indicate that, during the baseline period, the Prairies had a 93% chance of exceeding a WD of 100 mm, and a 35.8% chance of exceeding a WD of 300 mm. Projections under climate change indicate no change in the probability of exceeding WD of 100 mm, but point to an increase of over 10% in the probability of exceeding a WD of 300 mm. For the warmer southern Prairie region mentioned above, probabilities of exceeding a WD of 300 mm increases from 50.4% for the baseline period, to 64.9% under climate change.

CONCLUSION

Projected values for important agroclimatic indices suggest unchanged or broadly favourable conditions for crop production under climate change, particularly if the projected moderate increase in moisture deficits is managed well. When viewed from the perspective of exceeding critical temperature and moisture conditions, however, the potential for substantially increased risk emerges. Undoubtedly, crop production will adapt to different climatic regimes as it has in the past (Olmstead and Rhode, 2011). A couple of lessons can be drawn from this: i) although agroclimatic indices provide broad information regarding the potential for growing defined categories of crops in a given region, they do not capture the risks associated with climatic variability and extremes; ii) it is important to capture the magnitude of changes
to critical climatic thresholds, and to depict climatic variability such that associated risks to production are determined in conjunction with potential for production.

These findings indicate that the Canadian Prairies are projected to provide increased opportunities for the production of high value agricultural crops, but with increased risks that could frequently lead to yield reductions or crop failure. The implications of this for global food security are important in that fluctuations experienced within Canadian agricultural production due to climatic variability will be reflected in corresponding fluctuations in the availability and price of staple foods internationally due to Canada's role as a major contributor to global food supplies.

REFERENCES


8. ROLE OF TIDAL LOWLANDS FOR FOOD PRODUCTION IN THE HUMID TROPICS

Bart Schultz*

ABSTRACT

Lowlands, flood prone areas, can be found all over the world, along coasts, in river floodplains and as inland depressions. These are generally sensitive areas with a high ecological value and are basically unsuitable for development. However, due to their strategic location there is often a tremendous pressure to develop these areas for various types of land use. In this chapter the role of tidal lowlands for food production in the humid tropics is presented in light of the food needs related to population growth, increase in the standard of living and the on-going urbanisation. The advantages of the tidal lowlands, as well as the related risks and uncertainties of their development, will be illustrated.

INTRODUCTION

Lowlands, flood prone areas, can be found all over the world, along coasts, in river floodplains and as inland depressions. In their natural state these are, in many cases, sensitive areas with a high ecological value. Therefore they are basically unsuitable for development. However, due to their generally strategic location there is often a tremendous pressure to develop these areas for various types of land use. Initially after reclamation the land use is generally agriculture. However, in time the land use may gradually change towards an increasingly urban and industrial land use, as well as in certain cases, into recreational areas and man-made nature conservation areas (Schultz, 2006). Among the lowlands, the tidal lowlands

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have kind of a special place: due to the tidal fluctuation they may have the advantage that irrigation as well as drainage by gravity is possible, especially when the tidal movement is still taking place in the fresh water zone near the mouth of a river. In this chapter some characteristics of population, population growth and urbanisation will be presented. This will be followed by a summary of the opportunities of (tidal) lowlands in the humid tropics for food production as well as of certain risks that have to be taken into account in their development and management. The chapter will finish with a future outlook and some concluding remarks.

**POPULATION, POPULATION GROWTH AND URBANIZATION**

Population and population growth can be distinguished by three groups of countries: least developed, emerging and developed\(^1\). (Van Hofwegen and Svendsen, 2000; Schultz, 2001; Schultz et al. 2005 and 2009; International Commission on Irrigation and Drainage (ICID) 2009 and United Nations Department of Economic and Social Affairs, 2009).

The least developed countries are home to nearly 800 million people. In these countries, there is a rapid population growth resulting in an estimated doubling of the population by 2050. The emerging countries house almost 5 billion people (74% of the world's population). They still show a significant population growth, resulting in an estimated 30% increase in population by 2050. These countries also show a relatively rapid growth in the standard of living which results in changes to diet with the implication that more food needs to be produced than would follow from just the increase in population. The developed countries house almost one billion people and there is almost no population growth anymore. Some countries - like Germany and Japan - even show a certain decline in population.

In order to illustrate the role of tidal lowlands in food production in the humid tropics some characteristic data on Indonesia, Malaysia, Thailand and Viet Nam have been analysed, as well as some data for Asia and the world as a whole. These data are summarised in Table 1.

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\(^1\) Least developed countries. Most of the countries in Africa, several countries in Asia, 1 country in Central America and most of the smaller countries in Oceania; Emerging countries. Most of the Eastern European countries (including Russia), most of the countries in Central and South America, most of the countries in Asia (including China, India, Indonesia and Pakistan), and several countries in Africa; Developed countries. Most of the countries in Western and Central Europe, North America and some countries in Central and South America, the larger countries in Oceania and some countries in Asia.
Table 1: Population density with respect to geographic area and agricultural land
(Schultz et al., 2009 and United Nations Department of Economic and Social Affairs, 2009)

<table>
<thead>
<tr>
<th>Country/Continent</th>
<th>Total area in 10^6 ha</th>
<th>Arable land in 10^6 ha</th>
<th>Total population in millions</th>
<th>Total area</th>
<th>Arable land</th>
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<td>2050</td>
<td>2010</td>
<td>2050</td>
<td>2010</td>
</tr>
<tr>
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<td>192</td>
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<td>287</td>
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<td>39</td>
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<td>1,540</td>
<td>6,670</td>
<td>9,020</td>
<td>49</td>
</tr>
</tbody>
</table>

With respect to the topic of this chapter, population density with respect to geographic area and agricultural land as shown in Table 1 are of particular importance. It can be observed that with exception of Viet Nam, population densities with respect to geographical area are in the order of magnitude of the average for Asia and about three times as dense as the world average. The population density in Viet Nam, however, is significantly higher, about twice the average for Asia. If we look at the population densities with respect to arable land we see that Malaysia and Thailand have about half of the density for Asia and slightly below the world average. Indonesia and especially Viet Nam have significantly higher population densities on arable land than average.

**Population Growth and Urbanisation**

The population growth in the emerging and least developed countries will be concentrated in the urban areas. Most of these areas are in the lowlands. It is therefore expected that within 50 years 80% of world’s population will live and work in lowland, flood prone areas, most of them in cities (Schultz, 2008). In order to achieve or maintain food security a significant change will be required from smallholder farming towards food production for the urban population (Schultz et al., 2009). This implies an increase in farm size and production of higher value crops on land surrounding urban areas.

An example of rapid urbanisation is shown in Figure 1 with the growth of Jakarta, Indonesia from 1972 to 2005. In Figure 2 the change in percentage of urban population from 1950 to 2050 is shown for the four humid tropical countries as well as for Asia and the world. Figure 3 shows the growth of the urban population and rural population as derived from population data described above and Figure 2. The same has been done for the developed, emerging and least developed countries, as well as for the world as a whole (Figure 4). From these figures it can be derived that the urban population has significantly increased and will increase further in the future, especially in the emerging countries. What can also be derived from Figures 3 and 4 is that in the emerging countries the rural population has peaked and...
that in the coming decades a reduction may be expected. For the least developed countries a certain growth in rural populations may still be expected.

**Figure 1.** Growth of Jakarta over thirty years

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### OPPORTUNITIES OF LOWLANDS IN THE HUMID TROPICS FOR FOOD

Based on the developments outlined above, the following challenges with respect to food production and security are applicable (Van Hofwegen and Svendsen, 2000, Schultz, 2006, Schultz et al., 2009):

- to feed the growing world population, especially in the emerging and least developed countries, at affordable prices;
- to improve the standard of living and environmental conditions in the rural areas;
- to develop and manage land and water in a sustainable way during coming decades especially in emerging and least developed countries.

The (tidal) lowlands, especially in the humid tropics, may contribute significantly to cope with these challenges because of their potential for food production:

- With adequate water management, flood protection where required, farming practices and post harvest provisions, three harvests of rice per year of on average 4 - 8 tons each can be obtained (Figures 5 and 6). With respect to this it has to be realised that despite the high population density all four countries in the humid tropics are food self sufficient in rice. In addition, Thailand and Viet Nam are respectively the first
and second rice exporters in the world. By far most of this rice comes from lowland areas, especially in the Chao Phraya (Thailand), Mekong and Red River (Viet Nam) floodplains and deltas;

**Figure 2.** Increase in percentage of urban population in Indonesia, Malaysia, Thailand, Viet Nam, Asia and the world over 100 years

**Figure 3.** Growth of urban (left) and rural (right) population in Indonesia, Malaysia, Thailand and Viet Nam over 100 years
The agricultural schemes that were developed during the last decades have a rational layout, with relatively large and rectangular parcels. Due to this, mechanisation and increase in farm size are easily possible; there are still opportunities in several lowland areas to go from single cropping to double and even triple cropping.

**Figure 5.** Rice field in the tidal lowlands in Indonesia with a yield of the first rice crop of 8 tons per ha (left) and combine to harvest the rice in a mechanised way (right)
This underlines the importance of adequate water management infrastructure, good operation and maintenance, and last, but not least of stakeholder (farmer) participation and commitment. In the tidal lowlands in Indonesia this is being, or can be established very well with movable flapgates in the tertiary canals and flapgates, combined with vertical sliding gates in the secondary canals (Figure 6) in combination with the establishment of water users associations (WUA) that have a legal status (Joint Working Group, Ministry of Public Works and Rijkwaterstaat, 2006a and b, and Suprianto et al., 2010). For the operation of the water control structures in the tertiary canals, agreement can be relatively easily obtained among the up to 16 farmers that have their fields in the concerned tertiary block. The problem with the water control structures in the secondary canals is that there is generally no agreement among the about 125 farmers that have their fields in the concerned secondary block, on the operation rule of these structures, resulting in their inadequate performance.

In several of the lowland schemes, medium to long-term problems may be expected due to land subsidence and/or sea level rise (Rahmadi et al., 2010). Generally there is a global realisation of the possible impacts of sea level rise, such as increased risk of flooding and salinity intrusion. For example, the effects for the Mekong Delta in Viet Nam were clearly presented by To Quang Toan et al. during the 8th Annual Mekong Flood Forum in May 2010, Vientiane, Lao PDR.

However, there is a general unawareness and neglect of the possible effects of land subsidence in tidal lowland areas in the humid tropics. In order to understand this problem it has to be realised that the upper layers in lowlands generally consist of clay and/or peat. After reclamation of the clay soil there will be a certain subsidence, but it will remain within a few decimetres. The same holds true for reclaimed tidal lowlands with clay soil where most of the subsidence has already taken place. With peat soils, however, the story is completely different and reclamation subsidence and oxidation of 0.10 - 0.15 m/year may be expected. This subsidence far exceeds the possible impacts of sea level rise (Figure 7) (Intergovernmental
Panel on Climate Change (IPCC), 2007, Rahmadi et al., 2010). The consequence of these processes is that for reclaimed peat soils after a period of 10 to 15 years drainage by gravity will have to be replaced with drainage by pumping. Under the climatic conditions of the humid tropics, drainage by pumping is generally not affordable for agricultural land use. Due to this the areas become waterlogged and those who are exploiting these areas will leave. It is therefore of major importance that the remaining peat soils in the tidal lowlands not be reclaimed but be preserved, unless it is known that after disappearance of the peat soil, drainage by gravity will still be possible. For Indonesia, for example, this implies that out of its 20 million hectares of tidal lowland only 8 million hectares are suitable for agricultural exploitation (Suprianto et al., 2010).

**Figure 7.** Sea level rise and subsidence of peat soil after reclamation, based on the highest forecast of the Intergovernmental Panel of Climate Change (2007) and the expected subsidence and oxidation in the humid tropics. For subsidence and oxidation of peat the maximum has been set at 4.00 m, while it may be supposed that by that time the land will be under water.

With respect to agricultural water management it has to be realised that only three parties are really in charge (Figure 8) (Schultz et al., 2005). These concern the Government for policy, legislation and the construction, operation and maintenance of large water bodies and main structures of crucial importance; the irrigation and drainage agencies for the main and distributary systems and last but not least the farmers, generally for the field systems. This implies that when these three parties agree on how the systems will have to be operated and maintained, there will generally be high returns by means of good yields per hectare. However, when there is no agreement among these three parties, insufficient measures with respect to operation and maintenance will be taken, systems will decay and yields will be
significantly below the achievable level. All other parties as shown on the right side of Figure 8 are of importance, but at the end of the day they are only contributing and the key for success is with the responsible parties.

**Figure 8.** Actors in agricultural water management

<table>
<thead>
<tr>
<th>RESPONSIBLE</th>
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<td>Main and distributary systems</td>
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<td>Field systems</td>
</tr>
</tbody>
</table>

**FUTURE OUTLOOK**

With respect to the future outlook, the following items are of relevance:

- There is a general understanding that global food production will have to be doubled in the forthcoming 25 - 30 years. There is also an understanding that 80 - 90% of this increase will have to come from existing cultivated land and only 10 - 20% from new land reclamation. In rainfed areas without a water management system, rainwater management and improvement of livestock and fisheries may result in some progress, especially in the livelihood of poor smallholder farm families. There is, however, no way that the cultivated area without a water management system can contribute significantly to the required increase in food production (with the additional threat posed due to global climate change). Due to this the share of irrigated and drained areas in food production will have to significantly increase, especially in the emerging and least developed countries. This can be achieved either by installation of irrigation or drainage systems in areas without systems, improvement or modernisation of existing irrigation and drainage systems, installation of irrigation systems in rainfed areas with a drainage system, or installation of drainage systems in irrigated areas. In addition improvements in the institutional aspects of system management need to be considered, like increased participatory management of irrigation and drainage systems (Schultz, 2003 and Schultz et al., 2009).
On the other hand due to urbanisation, industrialisation and various other processes agricultural areas are taken out of production which aggravates the problem. In Indonesia, for example, about 40,000 - 50,000 ha per year of agricultural land is taken out of production due to urbanisation.

- Modernisation of irrigation and drainage systems will be required at a large scale and in combination with water saving irrigation techniques and practices where appropriate. In light of this the development of sprinkler and drip irrigation systems is promising. Over the past three decades globally 44 million hectares of such systems have been installed, which is in fact a very rapid development (International Commission on Irrigation and Drainage (ICID), 2010).

- In addition to modernisation at a large scale, flood protection will increasingly be needed. The value of the crops per hectare is rising and farmers in the lowlands will not accept flooding of a significant part of their crop anymore. In light of this the policy that the government of Viet Nam has recently adopted for the Mekong Delta is quite interesting. In essence this policy concerns a high level of protection for the higher parts of the delta, protection of the lower levels of the delta in such a way that two crops can be grown annually and these areas are inundated during the peak of the annual floods enabling the spreading of fertile natural sediments over the fields. Finally no protection for the deepest parts of the delta and using them as storage areas. Also the distinction of types of flooding as beneficial or damaging floods is interesting (Figure 9).

The developments as outlined above, with on the one hand the growth of the population and rapid urbanisation, especially in the emerging countries, and on the other hand the specific physical conditions in the (tidal) lowlands, will require that countries have a development
and management strategy on maintaining food security, as well as on the role allocated to the tidal lowlands in achieving this objective. In the development of such a strategy, the short, medium and long-term perspectives need to be taken into account.

CONCLUSIONS

- (Tidal) lowlands in the humid tropics have a tremendous potential to significantly contribute to food production.
- However, existing cultivated (tidal) lowlands may have to be improved. For new reifications, careful selection of areas, as well as of the development approach will be of major importance for success.
- In such approaches the specific physical conditions have to play an important role in order to prevent reduced benefits from generally considerable investments.

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9. WATER MANAGEMENT AND FOOD SECURITY IN CENTRAL ASIA

Victor Dukhovny*

ABSTRACT

Central Asia is a vast, land locked region comprised of five independent countries: Uzbekistan, Turkmenistan, Tajikistan, Kyrgyzstan, and Kazakhstan. Due to the arid nature of the regional climate, irrigated agriculture is a necessary practice and the two major rivers, the Amu Darya and the Syr Darya, are heavily used for irrigation. Although most of the region has rates of food insecurity below 11%, in Tajikistan, the country with the lowest cultivated area, over 30% of the population is undernourished. Rapidly growing populations in rural areas coupled with shifting diets and an anticipated warmer climate will place increasing pressure on water resources for food production. Deteriorating water infrastructure and rising use of water for hydropower have reduced the reliability of water supply for farmers and low irrigation efficiencies have resulted in low yields per unit of water. Improved irrigation technology and crop management, integrated water management at the basin level to share water within an irrigated region and water governance to oversee water use of all sectors is critical to food security in the region.

INTRODUCTION

Central Asia is a vast, land locked region with densely populated oases located along the upper and middle reaches of two great rivers and their tributaries and in irrigated areas and deltas in their lower reaches. The region is comprised of five independent countries: Uzbekistan,
Turkmenistan, Tajikistan, Kyrgyzstan, and Kazakhstan (Figure 1). Geographical features vary from deserts, to permafrost, high plateaus, mountains, and steppes and temperatures vary significantly with altitude. Most of Central Asia has an arid climate. Scant precipitation (less than 350-400 mm/year), extremely low humidity (22-40% in summer), high evaporation rates (maximum 1700 t/year), and abundant solar radiation are major climatic features of this region.

Major rivers of the region include the Amu Darya, the Syr Darya and their former tributaries the Zarafshan, the Murghab, the Hari Rud and major bodies of water include the Aral Sea and Lake Balkhash. Virtually all of the water in the Central Asia region originates from permanent snowfields and glaciers in the Tian Shan Mountains in Kyrgyzstan and Tajikistan and is carried for over 2000 km by the Amu Darya and the Syr Darya to Kazakhstan, Turkmenistan and Uzbekistan, and into the Aral Sea (UNDP 2005a).

Central Asia has a rich culture and heritage and a diversity of religions and ethnicities. The region has been closely tied by its nomadic peoples and the Silk Road acted as a crossroads for the transport and trade of goods and people throughout history. The current total population within Central Asia is over 61 million and almost half live in Uzbekistan (Table 1). An average of 41% of the people lives in urban areas although this varies widely from 26% in Tajikistan to 58% in Kazakhstan. Per capita GDP also varies widely within the region from a high of USD 11,800 in Kazakhstan to a low of USD 1900 in Tajikistan. These numbers parallel the proportion of the population which lives below the poverty line varying from 12 to 60%.
Table 1: Population and economic data

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<tr>
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</thead>
<tbody>
<tr>
<td>Kazakhstan</td>
<td>15,460,484</td>
<td>0.4</td>
<td>58</td>
<td>11,800</td>
<td>12 (2008)</td>
<td>NA</td>
</tr>
<tr>
<td>Turkmenistan</td>
<td>4,940,910</td>
<td>1.14</td>
<td>49</td>
<td>6700</td>
<td>30 (2004)</td>
<td>6 (200)</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>27,865,738</td>
<td>0.9</td>
<td>37</td>
<td>2800</td>
<td>26 (2008)</td>
<td>11 (2007)</td>
</tr>
<tr>
<td>Central Asia</td>
<td>61,263,247</td>
<td>1.15</td>
<td>41</td>
<td>5200</td>
<td>28</td>
<td></td>
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</tbody>
</table>

1 Number in brackets is the year data were estimated. 2 Purchasing power parity


CURRENT STATE OF FOOD SECURITY AND WATER MANAGEMENT IN CENTRAL ASIA

Background

Due to the arid nature of the regional climate, irrigated agriculture is a necessary practice in Central Asia and has been carried out for centuries. In Tajikistan, Turkmenistan and Uzbekistan all or most of the cultivated area is irrigated (Table 3). Some 22 million people depend directly or indirectly on irrigated agriculture and in rural areas it supports 60-70% of the population (Dukhovny and Sokolov, 2003). Irrigated agriculture lost most of its profitability during the 1990s and early 2000 due to the sharp decline in world crop prices and farmer net incomes declined from USD 500-1600 to USD 100-200 (Dukhovny and Sokolov, 2003). The weakened economy in Central Asia and the considerable drop in national per capita income resulted in a drastic decrease in subsidies and support for the agricultural and water sectors. Procurement of agricultural machinery, fertilizers and other chemicals declined and water infrastructure, especially at the on-farm level, deteriorated. As a result, water supplies and land conditions worsened drastically, affecting crop productivity. Introduction of market mechanisms into the agricultural sector (privatization, restructuring large state farms and collective farms into hundreds and even thousands of small private farms) was not accompanied by reestablishment infrastructure appropriate for commodity production. As a result, problems have arisen in servicing new private farmers and in procuring agricultural inputs.
Crop Production

Production of major agricultural products such as wheat, to ensure minimal food security in Central Asia strongly depends on available croplands and there are widely different growing conditions across the region (Table 2). Kazakhstan has a huge land area where wheat grows on dry land and is the main exporter of wheat; Uzbekistan and Turkmenistan possess enough irrigated area that they could produce sufficient amounts of cereals for their people for a short period. Difficulties with production of sufficient cereals remain in Kyrgyzstan and Tajikistan which have the lowest irrigated areas (Table 3) and Tajikistan annually imports up to 700,000 tons of cereals (Yokubzod, 2011). The production levels of vegetables and meat are similar to consumption levels in all countries, but all have a deficit in oil and sugar (Yokubzod, 2011).

The food security situation in Tajikistan is the worst in the region (Table 1) in large part due to a series of natural disasters that plagued the country in 2007-2008. According to the FAO Food Security Indicators, the proportion of the population in Tajikistan that is undernourished reached 30% in 2007 and more recently Fumagalli (2008) reported that in the spring of 2008, 1.68 million people in rural areas were food insecure (34% of the rural population) and of those, 11% were severely food insecure. The situation in urban areas was similar: 33% of urban population was food insecure of which 15% had a severe deficit.

<p>| Table 2: Wheat, milk and meat production in 2005-2007 (and compared to 2000-2002) |
| Wheat  | Milk       | Cattle Meat |</p>
<table>
<thead>
<tr>
<th>1000 MT</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Kazakhstan</td>
<td>13 709 (3.5%)</td>
<td>4874 (4.6%)</td>
</tr>
<tr>
<td>Kyrgyzstan</td>
<td>833 (-6%)</td>
<td>1173 (1.1%)</td>
</tr>
<tr>
<td>Tajikistan</td>
<td>---</td>
<td>507 (7.7%)</td>
</tr>
<tr>
<td>Turkmenistan</td>
<td>2931 (8.4%)</td>
<td>1466 (3.8%)</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>6118 (8.2%)</td>
<td>4777 (5.7%)</td>
</tr>
</tbody>
</table>

Data from FAO (2011)

| Table 3: Total, cultivated and irrigated areas of Central Asia |
|-------------------|-------------------|-------------------|-------------------|
|                   | Total Area¹ (1000 ha) (2008)³ | Cultivated Area¹ (1000 ha) (2008) | Actual Irrigated Area² (1000 ha) (2008) | % Total Actual Renewable Water Resources Withdrawn by Agriculture¹ |
| Kazakhstan        | 272 490            | 22 800            | 716              | 26 F (2002)            |
| Kyrgyzstan        | 19 995             | 1353              | 408              | 41 (1997)              |
| Turkmenistan      | 48 810             | 1918              | 2,179            | 97 F (2002)            |
| Uzbekistan        | 44 740             | 4620              | 4,392            | 107 F (2002)           |

1. Data from FAO Aquastat. 2. Data from Dukhovny and Stulina (2011). 3. Number in brackets is the date that data were obtained or estimated. F: FAO estimate.
Water Resources in Central Asia

Having established that irrigated agriculture is critical for food production, employment and livelihoods in Central Asia, understanding the complex geographic, historic and socio-political influences on the use of water resources is critical to future planning for food security in the region.

Two major rivers, the Amu Darya and Syr Darya are used for the irrigation of over eight million hectares in the five Central Asian countries. The Syr Darya is formed by the confluence of two major tributaries, the Naryn and Karadarya Rivers, has a length of 2200 km and a mean annual discharge of 37 billion cubic meters (BCM) with a range of 21 BCM to 54 BCM (Sharma et al. 2004). It originates in the Tien Shan Mountains of the Kyrgyz Republic, and passes through Tajikistan, Uzbekistan and South Kazakstan to the Aral Sea. The Amu Darya is formed by the joining of the Vaksh River originating on the Kyrgyz side of the Pamir Mountains and flowing through Tajikistan and the Pandij River originating in Afghanistan. The Amu Darya has a length of 2450 km, a mean annual discharge of 78.5 billion cubic meters (range of 47 BCM to 108 BCM) and passes through Afghanistan, Tajikistan, Uzbekistan, and Turkmenistan before reaching the Aral Sea (Sharma et al. 2004).

Irrigated agriculture uses roughly 100% of the total renewable water resources in Uzbekistan and Turkmenistan, 70% in Tajikistan and considerably less in Kazakhstan and Kyrgyzstan (Table 3). According to CAWATER info (2011) 79.7% of the water resources in the Syr Darya and Amu Darya in 1990 and 85.9% in 2009 were used for irrigation.

Water for Hydropower vs. Irrigation

After the creation of five independent Central Asian States in 1991, 18 rivers that used to be part of one country became shared between the five new countries and/or with other neighboring countries (Weinthal, 2006). Tajikistan, Kyrgyzstan, Kazakhstan, Turkmenistan, and Uzbekistan inherited an interconnected and sophisticated hydraulic infrastructure system from the Soviet era that was based upon the construction of large dams and water reservoirs in the mountainous areas of upstream countries (Tajikistan and Kyrgyzstan) and extensive irrigation infrastructure in the lowlands of Uzbekistan, Kazakhstan, and Turkmenistan to enable the production of cotton, fodder, wheat, fruits and vegetables. During Soviet rule, the diversion of water for irrigation from the Syr Darya River was so extensive (around 30 BCM) that in dry years irrigation needs were greater than the total flow in the river (Sharma et al. 2004). This necessitated the construction of a multi-year storage reservoir in the Kyrgyz Republic on the Naryn River to store water in wet years, and release it during dry years to provide irrigation water for cultivation. This reservoir, the Toktogul, was also provided with hydroelectric generating sets for producing electricity when water was being released but it was operated in an irrigation regime with nearly 75% of the annual releases occurring in the growing season and only 25% in the dormant or winter months.

Since the early 1990s however, demands for hydropower have risen substantially and reservoirs equipped to produce hydroelectricity have changed their operating regimes. This
has resulted in reduced water availability for irrigated agriculture in the middle and lower reaches of Amu Darya and Syr Darya in some dry years (Sorokin, 2011). The Toktogul reservoir, for example, is operated to store water during the growing season and release it during the winter when demand for electricity is high (Figure 2). As a result, droughts in 2007 and 2008 created a catastrophic situation with water availability in the Syr Darya River Basin because prior to the growing season there was insufficient water in the Toktogul Reservoir for irrigation of cropland. The reason for this shift is very clear: commercialization of hydropower and the growth in energy prices caused the increase in winter water release for power as opposed to meeting irrigation requirements in the summer. The financial benefits from energy production were increased by USD 30 million and caused losses to irrigated agriculture of USD 120 million (Dukhovny and Stulina, 2011).

Water storage and distribution infrastructure, much of it constructed over 50 years ago is aging and in need of repair. Due to the naturally high turbidity of the watercourses, reservoir sedimentation is an acute issue in Central Asia. In Uzbekistan, for example, total volume capacities of major reservoirs have decreased by about 20%. The direct loss of reservoir volume capacity leads to a reduced regulated capacity to combat water flow deviations during periods of drought or flooding.

Irrigation of Cropland

Traditional irrigation in Central Asia is surface or furrow irrigation which is known to have considerable freshwater losses but is popular because of its low cost and technology requirements. Average water use declined from 11740 m³/ha in 1990 to 9830 m³/ha in 2009 (CAWATER info, 2011), but less than 50% of this is effectively used. The remaining part
is lost, most of it on the unlined on-farm and inters farm canals (Sharma et al. 2004). If cropland is inadequately levelled, irrigation water is heterogeneously distributed on the field, which can reduce yield by 25–30% compared to potential yields. With furrows of 250–400 m or more in length, high percolation rates, high groundwater levels, soil salinity and water logging become common. According to data from the Scientific Information Centre, Interstate Commission for Water Coordination of Central Asia (SIC ICWC), common agrarian productivity has decreased significantly over the last 20 years – from 14300 to 12900 million USD in 2009 including on irrigated lands from 7820 to 7070 million USD (CAWATER info, 2011).

The intensification of irrigated agriculture in the region has also resulted in increased salinization of the drainage waters due to agricultural chemical contamination. The drainage water, mainly discharged into the Syr Darya and Amu Darya is diverted to croplands downstream and the saline water is recycled and contaminated further. Secondary soil salinization in the Ferghana Valley is widespread and increasing as the groundwater table rises to within 1 to 5m of the soil surface, due to heavy leaching and old, poorly functioning drainage systems (EC-IFAS, 1999). Due to salinization, irrigated lands continue to have diminished productivity, particularly in high saline areas although the degree of salinization has been reduced at whole.

The cost of putting new land under irrigation has increased dramatically over the past few decades. In the 1980s, developing irrigation infrastructure cost USD 3000-8000/ha but today it ranges from USD12,000-18,000/ha requiring significant investment on the part of the farmer and water user association.

**PRINCIPLE FACTORS OF FOOD DEMAND AND AVAILABILITY IN CENTRAL ASIA**

Sustainable food security of each country and the Central Asian region as a whole depend on major factors that should reflect a common principal: long-term balance between food demand and food availability that needs to be achieved at each stage of future development.

**Food Demand**

Population Growth: Growth rates are low in the two most populous countries of the region (Table 1) but nevertheless by the 2025 the population is expected to be between 71 and 96 million (Dukhovny and Stulina, 2009). Rapid population growth in rural areas has led to the most productive regions (Ferghana, Zerafshan, Khorezm, and Gissar Valleys) experiencing average population increases of 1.5% per year during past years, equalling population densities of 300-500 per square km (UNDP, 2005). Due to high unemployment and meagre salaries, there has been a recent migration of about 2 million people, mostly from Kyrgyzstan and Tajikistan, to find jobs in Kazakhstan and Russia. Such migration has created two positive features for food security by reducing demand for food and increasing the financial capacity.
of the population. This is particularly important in Tajikistan where, prior to the financial crisis in 2008, the transfer money from migrant workers was close to 50% of GDP (World Bank, 2010). It has now dropped to about 30%.

Diet: The western definition of a food basket with a prevalence of livestock products is very different from the traditional Central Asian basket as the latter demands less water and land to produce. Deciding which food basket or diet to promote is very important from the point of view of population health, water conservation and the state economy. Dietary energy supply has increased in all of the Central Asian countries over the last 20 years and varies from a low of 2130 kcal/person/day in Tajikistan to a high of 3360 kcal/person/day in Kazakhstan (FAO, 2011). Of the major food commodities consumed, wheat flour consistently accounts for about half of the calories (compared to 17% in Canada) although meat and dairy consumption have increased dramatically over the last century (Dukhovny and Stulina, 2011).

Degree of self sufficiency of population: Self sufficient food production depends on the promotion by state and local authorities of homestead plots sometimes limited to 0.06 ha/family in densely populated areas in Kyrgyzstan, Tajikistan, Uzbekistan, and up to 0.5ha in Turkmenistan, organization of special garden plots for the urban population outside of the cities; and permission and ability to keep livestock, sheep, goats, chicken etc. Self-sufficiency of the rural population for food is significant in Central Asia. Dukhovny and Stulina (2011) report that the portion of food from private home plots is 50% in Kazakhstan and Kyrgyzstan, 42% in Turkmenistan, 36% in Uzbekistan and 23% in Tajikistan.

Food Availability

Like food demand, factors of food availability depend heavily on government policies especially with regards to lands, water and investment.

Land: includes land ownership, rent and property; size of farms (0.4-2 ha in Kyrgyzstan; 5-30 ha in Kazakhstan and Tajikistan; 3-150 ha in Uzbekistan and a very broad range in Turkmenistan), forms of cooperation; planning of crop patterns (strict state regulations in Tajikistan, Turkmenistan and Uzbekistan), system of land registration and its ability to change and sell, protection of lands and pasture; state organization (or support) of extension services and agrarian education.

Water: includes water policy, support and development of irrigation, allocation responsibilities between the government and the public-private sector (Water User Associations) for water supply and operation of irrigation networks; water conservation; support and attention to water stability; support and responsibility for reclamation works.

Investment: includes subsidies, tax for lands; payment for water; sponsorship of water management organizations and part reclamation of lands, donor involvement and privilege for promotion of effective use of water and lands.
Climate Change: The natural water deficit makes the region susceptible to climate change. All scenarios predict an increase in temperature with a resulting growth of water consumption by at least 10-15% in the region. By 2050 volume of water resources will probably be reduced for the Amu Darya by 10-15% and the Syr Darya by 2-5% (Stulina, 2009). The frequency of dry year occurrence was 4.25 years from 1945-1965 but increased to 3 years from 1980 to 2004.

The probability of experiencing wet and dry years (25% and 75% respectively) and extreme years (10% and 90%) has increased 1.4 and 2 times (Dukhovny and Stulina, 2011). Glacier melting will also be accelerated by the forecast increase in temperature change. Glaciers and permanent snowfields that supply the region’s surface water are already shrinking. For example, the Pamir-Alai glacier which feeds into the Amu Darya lost 10% of its ice area (11% of its volume) between 1960 and 1980 (INSTAAR, 1998).

Although climate change will result in a longer growing season and therefore increased potential for crop productivity, achievement of this forecast is possible only under effective agronomic practices, and the availability of all necessary inputs including water. The forecast increment of days with high temperatures may lead to plant stress under low water availability. Yield losses could be 9-15% cotton and cereals, 10-20% for rice, 10-50% for vegetables, melons and gourds (Stulina, 2009).

**INCREASING FOOD PRODUCTION THROUGH INCREASED CROP YIELDS AND BETTER WATER MANAGEMENT**

Future increases in cultivated areas are limited by a lack of good lands in some areas, a common scarcity of water and a large net cost of new irrigated construction and development. The focus of attention should be on increasing yields and productivity and reducing the difference between actual and potential land productivity. Actual yields of cereals, vegetables and fruits are often less than half their potential yields (Dukhovny and Stulina, 2011). More efficient use of fertilizer, higher yielding crop varieties that are nutritious and drought resistant, improved land management, soil fertility and cropping techniques as well as better access to information, credit and insurance for producers, extension services and technical skills all have a role to play in raising food production. Central to all these however, is the establishment of irrigation infrastructure and water management that will deliver a reliable water supply to the farmer. Current water deliveries to irrigated areas often deviate from schedules and the unreliability of water supply results in crop and livelihood losses as well as a reluctance to invest further in agriculture.

Development of improved irrigation technologies, Integrated Water Resource Management (IWRM) within irrigated areas to improve water resources management, water governance at the basin level to strengthen collaboration between states for the creation of a guaranteed regime of water delivery, and the establishment of a strong state policy oriented towards food security are key to providing Central Asia with the means to ensure the well-being of its people.
**Improved Irrigation Technologies**

The improvement of on-farm irrigation systems and the introduction of low cost water saving irrigation technologies are key components to reduce agricultural water demand. Increasing water use efficiency (WUE), defined as the amount of plant material produced per unit of water transpired, is a way for arid and semi-arid areas to increase their agricultural production. Work by McGill University and SIC ICWC in the Ferghana Valley of Uzbekistan (Webber et al. 2006) showed that alternate furrow irrigation and deficit irrigation practices can reduce irrigation water requirements and increase water use efficiency. Consistent water savings of close to 25% were realised with alternate furrow irrigation over conventional furrow irrigation. When used in combination with deficit irrigation scheduling, water savings were as large as 50% as compared to the recommended irrigation volumes, with no yield reductions. However, the success of these technologies depended largely on the ability of the crop to withstand and/or adapt to water stress. Green gram’s water use efficiency was twice that of common bean. When less water was applied to green gram, WUE doubled as compared to the recommended irrigation amounts. Further work testing the tolerance of these crops to high levels of gypsum salts common to the region showed that acceptable yields were attained at the highest level of salinization (ECe of 7.4 dSm\(^{-1}\)) (Webber et al. 2009). This research suggests that growing legumes as a second crop after the winter wheat harvest is a means of increasing rural food security and improving land fertility.

**Integrated Water Resource Management (IWRM)**

IWRM promotes the collaboration of all organizations involved in water resources management (including surface, ground and return waters) across sectors including irrigated agriculture, hydropower, drinking water and industrial users, and between the hierarchical levels of water governance including basin, sub-basin, irrigation system, water user associations with the farm as the end-user. Sector interests must be reconciled to enable joint use of shared water resources in accordance with agreed schedules and to allow one sector to use the wastewater of others. Situations where each water management organization in the hierarchy develops its own approach that may disagree with the ultimate IWRM goal of getting maximum water efficiency for the area must be eliminated. Problems are often due to poor management quality rather than water deficits. Conflict resolution mechanisms must be developed to deal with conflicting interests.

IWRM has the potential to lead to equitable, sustainable, and guaranteed water availability resulting in reduced production losses due to disrupted water supply schedule. It creates an environment that attracts internal and external investments which favours an increase in employment and income growth. For example, the national income of the Kazalinsk and Aral regions of the Kzylorda oblast in Kazakhstan nearly doubled during 2002-2006 due to sustainable use of the Syr Darya delta water (Sokolov, 2011). IWRM creates a sustainable drinking water supply and improves water quality in rivers and other sources, and contributes to better health of the population. By recognizing the principal role of water for ecosystems and ensuring water release for natural demands, IWRM promotes the
recovery and protection of the environment. IWRM also enables the coordinated use of water energy to increase hydropower production, which furthers a stable power supply to the population during peak periods. Public participation, information exchange, openness and transparency of the water resources management system are also integral parts of IWRM, not only in the water management process, but also in financing, planning, maintaining and developing water infrastructure.

IWRM is moving forward in Central Asia. In the Ferghana Valley, a very important area for crop production, the conception of IWRM was coordinated and approved by all water authorities in Uzbekistan, Kyrgyzstan, and Tajikistan in May 2003 (Dukhovny and Stulina, 2011). It is not an easy task to provide guaranteed and equitable water distribution over an entire irrigation system but when water of sufficient quality is delivered in line with planned amounts, increases in productivity of water and land resources may be expected. Water users participated with more precise specifications of command areas for each irrigation canal, assessment of their water demands, and accounting for additional available water sources (groundwater, return water). Adjusting water supply, rotation and use depending on weather and economic conditions, as well as improving hydraulic measurements and record-keeping at all levels of the water management system, were also their responsibility. To tackle issues as they arose, it was necessary to establish extension services that assisted water users in the introduction of new technologies, advanced practice of planning and production, and solving water distribution problems.

The project rendered technical assistance in inspections and additional equipping of flow-measuring structures on pilot irrigation canals (an enormous program was implemented to establish water-metering systems within pilot WUAs). This activity allowed the establishment of proper water record-keeping on the pilot canals and within WUAs, making the water distribution process more transparent. The project started real-time management of the water delivery process on pilot irrigation canals and within pilot WUAs in the form of monitoring and updating the planned water supply schedule based on water user applications taking into account weather conditions during a growing season. This is the first step towards equitable and rightful water distribution and, at the same time, an attempt to reduce unproductive water losses.

Introducing IWRM in the Ferghana Valley has shown that the involvement of water users at the community level allowed considerable improvement in the efficiency of water use and reduced water withdrawals by more than 25% (Figure 3). Crop yields also increased between 18 and 64% (Dukhovny and Stulina, 2009).

**Water Governance**

Sustainability of water supplies starts at the level of transboundary water management as it is impossible to speak about sustainability if upstream riparian organizations regularly change the regime of water releases from the reservoirs located on their territories. Transboundary water resources management is therefore critical to the establishment and proper operation of basin
organizations. An ongoing project of the United Nations Economic Commission for Europe (UNECE) “Regional Dialogue and Cooperation on Water Resources Management” aims to empower the countries of Central Asia to develop and implement mutually acceptable, long-term solutions to improve cooperation on transboundary water resources. This will be done by enhancing the regional dialogue and strengthening the capacity of regional institutions for water resources management (UNECE 2010). Rules to establish basin organizations depending on their objectives and fields of activity and procedures of arbitrage, evaluation of damages and their compensation, implemented by basin organizations need to be developed. Procedures for adjusting national quotas, physical infrastructure and agreed upon procedures for multi-year regulation of river runoff and its control; participatory water resources management; mechanisms for supporting sustainable operation of local water organizations are all part of creating a sustainable water supply for food security in Central Asia.

**Figure 3.** Reducing the water diversion into the South Ferghana Canal due to introduction of IWRM (Dukhovny and Stulina, 2009)

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**State Policies**

The agricultural and water strategy of the state should be a framework to support the efficiency of IWRM and simultaneously promote the growth of food production. In 2003, cooperative farms yielded 20-100% more than private farms (Dukhovny and Stulina, 2011). Conditions for the development of private initiatives need to be created in order for the farmer to develop a long-term commitment to improving production through the input of his own skills. A financial system that links farmers, WUAs, processing and marketing and will support the stability and provide insurance for farmers and their partners needs to be established. Strong state planning in Tajikistan, Turkmenistan, and Uzbekistan needs to be reduced to no more than 50% of lands and farmers allowed to freely select crops to be grown and traded.
Achievement of food security is promoted also by regional differentiation of agricultural production. There is a need for close and stable long-term economic integration of the countries in the region, based on trust for one another. For example, on the basis of a regional Food Agreement, Kazakhstan could supply needy countries with wheat, milk and meat, and Tajikistan with fruits, vegetables, water and electricity (Yokubzod, 2011).

CONCLUSIONS

As populations rise and diets shift to include more meat and dairy products, crop production must increase to meet food demands. Food security in the five countries of Central Asia is strongly linked to the availability of water resources. More efficient use of fertilizer, higher yielding and resilient crop varieties, improved land management and cropping techniques as well as better extension services for those involved in the agricultural sector are all part of the solution to securing food supply for the region. All these factors however, depend on a reliable, high quality source of water. Integrated water resource management at the basin level and transboundary governance are both critical to sharing water resources between and within countries to achieve the most effective and efficient use of water for all sectors. IWRM and simple changes to irrigation methodologies introduced in the Ferghana Valley demonstrated that not only could water use be reduced but yields increased. State policies that provide a framework for increasing agricultural production and farmer incomes through improvements to land ownership, farm size, extension services, development of a financial support system and infrastructure appropriate for commodity production, and establishing a stable water supply are critical to food security in the region.

REFERENCES


10. WATER AND FOOD SECURITY IN SOUTHERN AFRICA

Aidan Senzanje*

ABSTRACT

In the less developed countries, there is an inextricable link between water and food security. This is primarily because the bulk of the economies in these countries are agro-based, the majority of the population derives their livelihood from agriculture and agriculture depends entirely on the availability and access to water, be it rainfall or irrigation. This chapter presents an overview of water and food security issues in Southern Africa (South Africa, Lesotho, Swaziland, Mozambique, Malawi, Zambia, Zimbabwe, Botswana, and Namibia) with an emphasis on water management. Rainfall in the Southern African region is variable and unpredictable between and within years, and economic development and agricultural growth are closely linked to rainfall during the growing seasons. All countries in Southern Africa suffer from some form of water stress: either physical or economic. As agriculture withdraws the highest proportion of freshwater resources in the region, efforts should be directed towards better management of agricultural water and increasing water productivity. Typical practices would include making better use of green water, micro-agricultural water management, increasing water productivity through managing hydro-climatic deficiencies and maximizing plant water-uptake capacity, and increasing agricultural resilience.

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INTRODUCTION

In the less developed countries, there is an inextricable link between water and food security. This is primarily because the bulk of the economies in these countries are agro-based, with the majority (almost 55%) of the population deriving their livelihood from agriculture (IFAD, 2010). Agriculture depends entirely on the availability of, and access to, water be it rainfall or irrigation. Whenever there is crop failure there is food insecurity due first to the inability to produce enough food and second, to the lack of financial resources to procure food from elsewhere. It would thus naturally follow that in order to improve food security in developing countries, it is important to pay attention to sustainable agricultural development through, among several other factors, better agricultural water management. Although many argue that agriculture is not the only answer to improving developing economies, reality on the ground has always shown that the transformation of an agrarian economy, where a large proportion of the population depends on agriculture, to an industrial economy is neither easy nor rapid.

In sub-Saharan Africa hunger affects 30% of the population and there are over 204 million malnourished people, including 33 million children (Merrey and Sally, 2006). It is the only region in the world where hunger is increasing. An estimated 40% of people in sub-Saharan Africa live below the poverty datum line and both income and human poverty are increasing (UNEP, 2002). In this sub-Saharan region, Southern Africa has seen a decrease in per capita caloric intake and an increased incidence of chronic and seasonal hunger. Among the several causative factors cited for the failure of the region to attain the important MDG 1 (eradicating extreme poverty and hunger by 2015 (UNDP, 2010)) is the impact of climate change manifested in recurrent droughts and floods. These reduce agricultural production which in turn affects economic development and food production leading to food insecurity. These challenging times call for concerted efforts to improve agricultural production. This paper presents an overview of water and food security issues in Southern Africa with an emphasis on water management. Southern Africa includes South Africa, Lesotho, Swaziland, Mozambique, Malawi, Zambia, Zimbabwe, Botswana, and Namibia.

POPULATION, ECONOMY AND AGRICULTURE OF SOUTHERN AFRICA

The Southern African countries under discussion have a combined population of about 119 million (Table 1) with an average population growth rate of 1.43%. The total GDP of the region is USD237 billion and is dominated by agriculture (Table 1) with the exception of Botswana and South Africa. Large shares of the GDP come from primary sectors of production such as agriculture and mining. Most Southern African countries, with the exception of South Africa, have small manufacturing sectors.

Despite the relatively high aggregate GDP, conditions vary between countries, especially with regard to social and economic growth. The region’s average level of per capita income (as measured by the Gross National Income, GNI) is less than USD500 for most countries except South Africa (USD2820) and Botswana (USD3100) (SADC, 2008). The widespread poverty in Southern Africa has been exacerbated in recent years by extreme floods and
droughts that have caused serious food shortages and food insecurity (SADC, 2008). Three countries in the Southern African region are in the 15 highest risk countries as measured by the Food Security Score (FSI). Zimbabwe is ranked number 1 (FSI = 0.80), Malawi is 6 (0.95) and Zambia is 15 (1.30). The Global Hunger Index (GHI), an indicator of a country’s hunger situation (IFPRI, 2010), varies in the region from moderate (South Africa) through serious (Botswana, Lesotho, Malawi, Namibia and Swaziland) to alarming (Mozambique, Zambia and Zimbabwe).

### Table 1: Population and GDP for Southern African countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Population (million)</th>
<th>Population Growth Rate (%)</th>
<th>Gross Domestic Product (USD billion)</th>
<th>Agriculture Sector Contribution to GDP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Botswana</td>
<td>1.9</td>
<td>1.94</td>
<td>8.7</td>
<td>1.6</td>
</tr>
<tr>
<td>Lesotho</td>
<td>2.1</td>
<td>0.12</td>
<td>1.4</td>
<td>7.1</td>
</tr>
<tr>
<td>Malawi</td>
<td>15.9</td>
<td>2.76</td>
<td>1.9</td>
<td>30.1</td>
</tr>
<tr>
<td>Mozambique</td>
<td>21.7</td>
<td>1.79</td>
<td>5.5</td>
<td>23.4</td>
</tr>
<tr>
<td>Namibia</td>
<td>2.1</td>
<td>0.95</td>
<td>5.5</td>
<td>9.6</td>
</tr>
<tr>
<td>South Africa</td>
<td>49.9</td>
<td>0.92</td>
<td>201.4</td>
<td>3</td>
</tr>
<tr>
<td>Swaziland</td>
<td>1.4</td>
<td>1.2</td>
<td>2.4</td>
<td>8.6</td>
</tr>
<tr>
<td>Zambia</td>
<td>11.9</td>
<td>1.63</td>
<td>5.4</td>
<td>16.7</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>12</td>
<td>1.53</td>
<td>4.7</td>
<td>18.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>118.87</strong></td>
<td><strong>1.43</strong></td>
<td><strong>236.9</strong></td>
<td><strong>-</strong></td>
</tr>
</tbody>
</table>

Source: SADC Trade, 2006; CIA World Factbook, 2010

Agricultural activities in the region include both commercial and subsistence farming. Livestock, cash and subsistence crops are produced in the region (Table 2).

### Table 2: Major agricultural products in Southern Africa (by tonnage and value)

<table>
<thead>
<tr>
<th>Country</th>
<th>Major Agricultural Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Botswana</td>
<td>Cattle (meat), milk, game (meat), small grain</td>
</tr>
<tr>
<td>Lesotho</td>
<td>Potatoes, milk, game (meat), wool, maize</td>
</tr>
<tr>
<td>Malawi</td>
<td>Potatoes, tobacco, maize, cassava</td>
</tr>
<tr>
<td>Mozambique</td>
<td>Cassava, cotton, maize, tobacco, sugar cane</td>
</tr>
<tr>
<td>Namibia</td>
<td>Cattle, roots &amp; tubers, milk</td>
</tr>
<tr>
<td>South Africa</td>
<td>Meat, chicken, maize, grapes, sugar cane</td>
</tr>
<tr>
<td>Swaziland</td>
<td>Sugar cane, cattle (meat), milk</td>
</tr>
<tr>
<td>Zambia</td>
<td>Maize, cattle (meat), tobacco, cotton</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>Cattle (meat), tobacco, cotton, sugar cane</td>
</tr>
</tbody>
</table>

Source: FAO, 2010
WATER MANAGEMENT FOR GLOBAL FOOD SECURITY

RAINFOREST AND ECONOMIC DEVELOPMENT

Climate has a significant impact on the economies of developing countries where agriculture contributes a significant share to the GDP. Like the rest of sub-Saharan Africa, rainfall in the Southern Africa region is characterized by both variability and unpredictability, between and within years. Rainfall deficits are exacerbated by soils with low moisture holding capacity, high evaporative demand and limited irrigation development (Barrios et al. 2008). For developing countries, rainfall can be an accurate indicator of a country’s GDP growth and it has been shown that the highest total and agricultural GDP growth rates occur during years with average or slightly above average rainfall (Ludwig et al., 2009). During years of below average rainfall, growth is severely reduced and generally the drier the year, the lower the GDP growth rate (Ludwig et al., 2009). In sub-Saharan Africa, rainfall variability contributes to reduced economic productivity and increased poverty (Brown et al. 2010). A World Bank study (WB, 2006) showed an extremely high dependence of Ethiopia’s economy on rainfall variations and in Mozambique, water related shocks depress the country’s GDP by more than one percentage point each year (AIKP, 2011). In Zambia, rainfall variability lowers the country’s agricultural growth by one percentage point each year and will cost the country USD4.3 billion in lost GDP over 10 years (AIKP, 2011). Rainfall variability contributes to risk aversion by farmers (i.e., farmers invest less) resulting in agricultural investments that are less profitable which in turn lowers agricultural production. It is evident that climate has significant effects on household income, agricultural productivity and economic growth in sub-Saharan Africa (Brown et al., 2010).

THE LINK BETWEEN WATER AND FOOD SECURITY

Many factors affect food security issues in Southern Africa including both bio-physical and socio-political issues affecting both production (supply) and consumption (demand). The link between water and food security can be presented in several ways, but for the southern Africa region it can be shown that factors influencing water availability and agriculture also directly affect food security.

Typical of developing economies, agriculture withdraws the highest proportion of freshwater resources (upward of 75% on average) in the southern Africa region. Freshwater withdrawals by agriculture dominate total withdrawals in Malawi, Mozambique, Swaziland, Zambia and Zimbabwe (Table 3). In Namibia and South Africa agricultural withdrawals are dominant but are coupled with significant domestic use. For example in South Africa, the freshwater withdrawals are as follows: agriculture 62%, urban 23%, rural 4%, mining 6%, power generation 2% and afforestation 3%. The amount of fresh water consumed by agriculture ranges anywhere from 2000 to 24 000 m³/ha/yr (WRI, 2000; FAO, 2010).
Since agriculture is dependent on water (rainfall and irrigation), if there are water shortages, for example, a drier season than normal, the agricultural sector in the Southern African countries underperforms (i.e., low agricultural production of key crops). This makes Southern African countries particularly vulnerable to food security shortages as a result of any factor that affects agriculture. As an example, in many of the region’s rainfed systems, cereal yields average 0.5 t/ha against a potential of 3 to 5 t/ha (Rockström, 2003), due to low production potential, sub-optimal agricultural water management, and low investments in intensive agriculture. In sub-Saharan Africa, rainfed agriculture is practiced on 95% of the land, and 60% of the population depends on rain-based economies. Although the average annual growth rate of population has now declined to 2.2%, for 20 years the population of sub-Saharan Africa increased at a rate of between 2.3% and 3.8% (UNFPA, 2007) and demand for food continues to outstrip production from traditional rainfed systems by several fold.

Only 5% of the world’s total irrigated area of 275 million ha is in Africa and there is great disparity in irrigation development within Africa. For example, 5 countries (Egypt, Sudan, South Africa, Morocco and Madagascar) cover 19% of the land area and hold 60% of the irrigated area, while 28 countries covering more than 30% of Africa’s land area hold a mere 5% of the irrigated area. Very few countries in sub-Saharan Africa have developed the bulk of their irrigation potential. In Southern Africa, only South Africa has fully developed all its potential irrigable area while Mozambique, for example, has developed only 4% (Table 4). The lack of irrigated agricultural production coupled with erratic rainfall and suboptimal production strategies under rainfed agriculture results in a high risk of food insecurity in the region.
Table 4: Cultivated and irrigated area in Southern Africa

<table>
<thead>
<tr>
<th>Country</th>
<th>Cultivated Area (1000 ha)</th>
<th>Irrigated Area (1000 ha)</th>
<th>Irrigated Area as Proportion of Cultivated Area (%)</th>
<th>Irrigated Area as Proportion of Potential Irrigable Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Botswana</td>
<td>252</td>
<td>1.44</td>
<td>0.59</td>
<td>11</td>
</tr>
<tr>
<td>Lesotho</td>
<td>359</td>
<td>2.64</td>
<td>0.87</td>
<td>21</td>
</tr>
<tr>
<td>Malawi</td>
<td>3622</td>
<td>56.39</td>
<td>1.9</td>
<td>35</td>
</tr>
<tr>
<td>Mozambique</td>
<td>4750</td>
<td>118.12</td>
<td>2.51</td>
<td>4</td>
</tr>
<tr>
<td>Namibia</td>
<td>808</td>
<td>7.57</td>
<td>0.92</td>
<td>16</td>
</tr>
<tr>
<td>South Africa</td>
<td>15450</td>
<td>1498</td>
<td>9.53</td>
<td>100</td>
</tr>
<tr>
<td>Swaziland</td>
<td>192</td>
<td>49.84</td>
<td>25.96</td>
<td>53</td>
</tr>
<tr>
<td>Zambia</td>
<td>2384</td>
<td>155.91</td>
<td>7.71</td>
<td>30</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>3850</td>
<td>173.51</td>
<td>5.1</td>
<td>47</td>
</tr>
<tr>
<td>Total</td>
<td>31667</td>
<td>2063.42</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: FAO Aquastat, 2010

On the supply side of the food security equation there are several factors related to water that are driving the food shortage problem. These include factors limiting or reducing the amount of water available to agriculture for food production such as climate change, a shift to bio-fuel production, a decrease in production of key cereals, a need for the provision of environmental water, water quality deterioration, and increasing demand for water from other sectors like domestic and industry. On the demand side another set of factors increase food requirements including, increasing population, shifts in peoples’ diets, and urbanization. Some of these factors are discussed in the following sections, especially where they relate to water and food security.

WATER ISSUES IN SOUTHERN AFRICA

A large number of countries in sub-Saharan Africa experience significant water stress due to insufficient and unreliable rainfall, and changing rainfall patterns (ODI, 2009) leading to extreme events like droughts and floods. In Africa, approximately 200 million people (25% of the population) currently experience water stress (ODI, 2009). Water scarcity has a direct impact on food production and economic activities in most of the countries in the region, with the possible exception of Botswana and South Africa whose economies also rely on mining and industry, respectively. All countries in Southern Africa already suffer from some form of water stress: either physical or economic. Physical water scarcity is defined as insufficient water resources to meet all current needs, and economic scarcity means investments required to keep up with a growing water demand are constrained by financial, human or institutional capacity. South Africa suffers from physical water scarcity given that about two-thirds of the country has an arid to semi-arid climate with a mean annual...
rainfall of 450 mm (Schulze, 1997) and experiences periodic droughts and floods. The other Southern Africa countries experience economic water scarcity due to limited investments in water resources development. For most countries in Southern Africa, freshwater availability is below 1700 m$^3$ per capita/year (WRI, 2000) and water stress, as measured by the Water Stress Indicator (ratio of withdrawal to availability), ranges from low to very high.

Water stress in Southern Africa is caused by many factors but some of the more important ones include climate change (and variability), increasing population and dietary shifts, rising water demand, land degradation and deteriorating water quality. In South Africa, water is critical to socio-economic development. The country’s economy is expected to grow overall by about 6% in the next few years and this growth will need to be supported by water. This increased demand will create competition for water resources among the various sectors in the country with agriculture, the largest user, under pressure to use water more efficiently.

**Climate Change**

Climate change is expected to exacerbate an already fragile situation regarding water in Southern Africa. There will be major changes in rainfall events resulting in temporal and spatial shifts in the availability of water and increased likelihood of floods and droughts. Based on recent climate change modeling exercises for South Africa, it is anticipated that overall rainfall patterns will shift and areas like the Western Cape will experience less rainfall in the future compared to the past or present (Schulze, 2010). There will likely be reduced runoff in such areas and increased irrigation demand in summer which will directly affect agricultural production in South Africa. Reduced stream flows from reduced runoff will only serve to increase competition, and possibly conflict, between water users and water-using sectors. In eastern parts of the country, climate change is likely to result in increased rainfall and more runoff meaning more water will be available. Although this is taken as a positive development, there is a risk that rains of varying intensity and distribution may lead to problems of flooding and severe erosion (Schulze, 2010). Similar flooding scenarios are also envisaged for Mozambique and Namibia thus threatening food production in countries that are already vulnerable to food shortage problems. River basins, such as the Limpopo that spans Zimbabwe, Botswana, South Africa and Mozambique, where the bulk of water is used for irrigation, are already considered closed (or almost closed) meaning there are no more water resources left to allocate. Climate change will worsen this situation with negative effects on irrigated agriculture and rural livelihood activities.

**Population Increase**

As the population in the region increases and water resources remain finite or decrease, the amount of water available per capita decreases, creating conditions of water scarcity. Population growth in the sub Saharan region is one of the highest in the world and this increasing population will demand more water for rural livelihoods (where the bulk of the population resides) as well as for the production of adequate food supplies. The link between
population and water demand is almost exponential as illustrated by Rijsberman (2010); during the 20th century, the world population tripled but the associated total amount of water extracted for human use increased six fold.

**Land Degradation**

Land use changes leading to land degradation have both direct and indirect impacts on water resources availability. Indirectly, changes in land use impact hydrologic processes thus affecting rainfall locally and regionally. Deforestation generally results in reduced rainfall amounts overall. Directly and in the short term, land use changes may result in increased runoff into rivers and reservoirs. However, in the medium to long term, increased erosion results not only in reduced reservoir capacity and soil water holding capacity which limits water availability for all purposes including food production, it also reduces soil fertility. About 28% of South Africa’s land area is considered degraded affecting some 17 million people in the country. In Swaziland almost 95% of the land is considered degraded (affecting 948,000 people), Zambia 60% (affecting 5.8 million people), Zimbabwe 46% (affecting 5.4 million people), Namibia 35% (affecting 671 000 people), Lesotho 34% (affecting 941,000 people), Mozambique 28% (affecting 5.2 million people) and Botswana about 16% (affecting 477,000 people) (Bai et al., 2008). Land degradation reduces water productivity at field and landscape scales, and affects water availability, quality and storage (Bossio, et al., 2009). Such degradation impacts the water available to agriculture for food production leading to food shortages.

**Demand Management**

Increasing demand for water, whether intentional or not, leads to problems of water scarcity in the southern Africa region. For a long time, most water planners and managers in the region looked only at the supply side of water, i.e., building more reservoirs and exploiting groundwater. There was, and probably is still, very little thought put into regulating demand management to ease pressure on water supplies, although it would be beneficial to most countries in the Southern Africa region. South Africa has started to implement demand management of water and has a conservation (the minimization of loss or waste, care and protection of water resources and the efficient and effective use of water) and demand management (the adaptation and implementation of a strategy by water institutions to influence water demand and usage) (WC&DM) policy (DWAF, 2004). South Africa puts forward the following principles in water conservation and demand management:

- social equity,
- environmental sustainability,
- economic efficiency.

Agriculture, as the largest water consumer, is at the centre of the WC & DM and is expected to institute water conservation through efficient management and use of water practices to
minimize losses and waste. Agriculture is expected to adopt practices and measures (such as irrigation scheduling) that reduce water demand. A reduction in agricultural water demand means the saved water can be released to other sectors in the economy of South Africa.

**Dietary Shifts**

The rate of urbanization ranges from 1.2% per annum for South Africa to 5.3% per annum for Malawi (CIA World Factbook, 2010), although the bulk of the population still remains rural based. As populations in the Southern Africa region become increasingly urbanized and move into the middle class social status, their diets change from predominantly cereal based to more meat (and fish) based. The unintended consequence of this is an increase in water demand for food production. Meat-based diets require more water to produce compared to cereal-based diets. As an example, one would require about 1.3 m³ of water to produce a kg of wheat, up to 16 m³ of water per kg beef, and 22 m³ of water per kg soybean oil.

**Water Quality**

Water quality deterioration arises from point source or diffuse pollution and affects water availability and suitability for given uses. Sources of pollution are many and varied and include agricultural, mining, and industrial activities and urbanization. Polluted water has limited uses and conditions for its use may be sufficiently stringent to render it unavailable. Unavailable water leads to conditions of water scarcity. South Africa is currently facing very serious acid mine drainage water quality problems in the Gauteng region as a result of past mining activities that did not adequately take into account environmental considerations. All water that is currently affected by the acid mine drainage problem in South Africa is not available for any productive uses, and thus contributes to the problem of water scarcity in an already water stressed country.

**Access and Equity**

The availability of water for food production is also related to access and equity issues. Historically, in most Southern African countries, water access was based on the doctrine of water rights that were normally held in perpetuity and tied to land. In countries with a long colonial legacy such as Namibia, South Africa and Zimbabwe, the bulk of the population had no access to productive water (they had access to water for primary use) simply because they were marginalized and had no access to productive land. This resulted in such populations being unable to undertake intensive agricultural production and caused them to be perpetually food insecure. Even if there was adequate food in the country, their resource base was poor; they could not afford to procure food and therefore were dependent on food handouts from government or non-governmental organizations. It is only recently that there have been reforms in the water sector in Southern Africa (Movik, 2009) as a result of the concept of Integrated Water Resources Management, resulting in the bulk of rural populations now being able to access water for productive uses. South Africa’s water reforms
are particularly interesting because they include water allocation reforms whose main goal is to re-dress past imbalances in accessing and use of water, as well as trying to make sure that water use leads to economic growth, equity and job creation. Accessing water is only the first part on the long road to productive use of water in agriculture and ensuring adequate food production.

Even though access may technically be improved through legislation, equity remains elusive and results in agricultural production shortcomings and food security problems. Since water for food production needs to be tied to land, equity issues in water become compounded by land problems. In developing countries, the nominal land holding size is less than 0.2 ha per capita. In many countries in the Southern Africa region, equity issues in agriculture are still problematic given that in general the small scale rural farmer has a very small land holding with communal grazing compared to commercial farmers who tend to have large tracts of land with freehold title. In South Africa, land resettlement and restitution programs are underway but they are trailing behind expected targets (transfer of about 30% of land from white commercial farmers to the historically disadvantaged individuals (HDI) by 2015). More needs to be done and done urgently. Zimbabwe’s land reform is notorious for the way it was implemented and the consequences to both food production and the economy. Although in the long run the land reform is expected to improve agricultural production, in the short term it turned Zimbabwe from a food secure country to a food insecure country, and rendered the newly formed water institutions inoperative or non-functional.

Despite problems of water scarcity in Southern Africa, there is optimism that the food security situation in the region can be improved. Some of the proposed initiatives are low cost and have the potential to significantly increase food production per unit of scarce water resources.

**IMPROVING FOOD SECURITY IN SOUTHERN AFRICA THROUGH AGRICULTURAL WATER MANAGEMENT**

As previously discussed, the bulk of agriculture in the region is rainfed based. Improvements to rainfed agricultural production have the potential to uplift the livelihoods and food security situation of a large proportion of the population. Efforts should predominantly be directed towards better management of agricultural water and increasing water productivity. Agricultural water can either be blue or green and to some extent white water. Blue water, the bulk of water used in irrigated agriculture, is found in rivers, reservoirs and lakes, and has tended to be the preserve of supply side oriented water planners and managers. Green agricultural water is stored in the soil and plants and forms the bulk of water used in rainfed agriculture. Recent efforts aimed at improving water productivity in rainfed agriculture have focused on green water. White water is generally taken to imply water that is in vapor form, in transpiration and vapor exchange processes in crop production.

In agricultural production, blue and green water are considered as a continuum from rainfed agriculture (green water) through to irrigated agriculture (blue water). Rainfed
agricultural productivity is low compared to irrigated agriculture due to better water control in combination with other inputs such as inorganic fertilizers under irrigation (Figure 1). There is however, a greater of potential for improvement of rainfed production.

Any efforts towards improved agricultural water management for food security in Southern Africa have to deal with green and blue water. Several initiatives are available to improve agricultural productivity in the region including improved agricultural water management, increasing water productivity, and building resilience in agricultural systems.

**Figure 1.** Green-blue water productivity continuum (Vidal et al. 2010)

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**Improved Agricultural Water Management**

Agricultural water management (AWM) can be defined as those deliberate human actions designed to optimize the availability and utilization of water for agricultural purposes (IMAWESA, 2008). AWM involves all water inputs (rainfall as well as water supplied from surface and underground sources) used in agriculture (crops, tree crops and livestock) in the continuum from rainfed systems to irrigated agriculture. It includes agronomy, soil and water conservation, rainwater harvesting, irrigation and drainage. It also extends to the development of water resources for agriculture in interventions such as integrated watershed management and all relevant aspects of land management.

Improved AWM strategies include micro-agricultural water management which consists of small-scale technologies and practices such as low-cost water lifting technologies (e.g., treadle pumps), low-cost water application technologies (e.g., drip irrigation kits), technologies to capture and store rainwater either in small reservoirs or in the root zone (rainwater harvesting), conservation tillage and other soil nutrient and water conservation technologies.
WATER MANAGEMENT FOR GLOBAL FOOD SECURITY

(Merrey and Sally, 2006). These micro-technologies and practices help to increase water productivity and resilience of agricultural systems.

Regarding irrigation development it is argued that a high but feasible 3.6% annual increase in investments in irrigation would triple Africa's irrigated area to markedly improve food supply and nutrition, stabilizing inflation in food prices and slashing cereal imports (AIKP, 2011).

Increasing Water Productivity

One of the greatest challenges facing the southern Africa region is to increase water productivity (more crop output per unit of water in both rainfed and irrigated systems) with direct benefits such as increased food production, increased returns, and improved rural livelihoods. Rainfed yields for cereals are in the range of 0.5 t/ha and there is tremendous scope to increase water productivity to attain the potential yields of 5 t/ha. To be able to deal with hydro-climatic deficiencies such as mid season dry spells and seasonal droughts and to stabilize production, smallholder farmers should practice rainwater harvesting (RWH) and supplementary irrigation. (Wani et al., 2009). RWH aims at increasing available soil water by capturing rainfall and making sure that it infiltrates into the soil. RWH coupled with judicious fertilizer management has the potential to increase water productivity significantly. In addition, water management can be targeted to maximize plant water-uptake capacity, using crop and soil management to increase root water uptake (Karlberg et al., 2009). Table 5 summarizes techniques and practices that can be adopted to improve crop yields and water productivity.

Water productivity can further be improved by adopting multiple use systems (MUS). MUS allow water systems to have their water accounted for in several production processes, thus increasing the output per unit of water. Irrigation systems which use predominantly blue water are very amenable to MUS with a concomitant increase in water productivity.

Table 5: Techniques and practices to improve crop yields and water productivity (modified from Critchley and Siegert, 1991)

<table>
<thead>
<tr>
<th>Water management strategy</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase plant water availability</td>
<td>Dry spell mitigation, supplementary irrigation, off-season irrigation, recharge</td>
</tr>
<tr>
<td>• Ex-situ (external) water-harvesting</td>
<td></td>
</tr>
<tr>
<td>• In-situ water-harvesting</td>
<td></td>
</tr>
<tr>
<td>Evaporation management</td>
<td>Reduce non productive evaporation</td>
</tr>
<tr>
<td>Increase plant water uptake capacity</td>
<td>Increase proportion of water balanced flowing as productive transpiration</td>
</tr>
</tbody>
</table>

One of the challenges to increasing water productivity is the fact that cost of water tends to be subsidized (Rosegrant, et al., 2002) and is considered cheap in many countries including those in the Southern Africa region. Because it is subsidized, farmers have no incentive to use water efficiently or increase its productivity. However, with water scarcity becoming more widespread it will become imperative that water productivity is increased.
Increasing Agricultural Resilience

Resilience of agricultural systems has hitherto been an ignored aspect of rainfed food production. Resilience, which can be taken to include system robustness, adaptability, persistence and transformability, allows agricultural systems to withstand external and internal shocks and stresses that might negatively impact agricultural production. Many of the proposed measures to improve water productivity (e.g., soil and water conservation techniques) also help to improve the resilience of agricultural systems by allowing the system to weather external shocks (e.g., mid season dry spells, climate change). A substantial amount of research has been undertaken in Southern Africa on soil and water conservation techniques and practices to improve the resilience of rainfed systems.

In irrigated agriculture, irrigation itself is a way towards improving resilience of agricultural systems. An agricultural system that has irrigation has better water control; water can be applied to crops as and when it is required, and this normally assures high production and productivity. The problem with current irrigation practices is that water use efficiency can be low which implies that there is scope for improvement through reducing the non-beneficial use consumption of water. Realistically, there is not enough water to enable a large proportion of the population to access irrigation infrastructure for food production (Falkenmark and Rockström, 2004), so the focus will remain on trying to improve rainfed agriculture resilience.

Other ways of increasing resilience include breeding drought resistant or drought tolerant crop varieties, and crops that are resistant to pest and diseases. Such efforts are receiving substantial funding worldwide and will not be discussed here but suffice to mention that the impact would be even greater if breeding was coupled with better water management.

Policy Changes

For most of the proposed measures to work, there is a need for policy changes in the region. Policies should promote measures that improve agricultural water management and increase water productivity. Although this is a very important aspect of water and food security, and many publications have been devoted to it (e.g., Merrey and Sally, 2006; Kamara and Sally, 2004), it is beyond the scope of this chapter.

CONCLUSIONS

Water and food security are inseparable in Southern Africa. The bulk of the population is rural based and derives its livelihood and food from agricultural activities. Any factors that affect water availability directly impact on these key aspects of life. Water resources in the region are under stress, with implications on the ability of Southern Africa to produce enough food for its population. All countries, with the exception of South Africa, are food insecure. Although South Africa produces adequate food, there are still problems of localized food inadequacy, necessitating internal food redistribution. Botswana being an arid country...
has adopted a strategy of importing food to meet its requirements. The rest of the region suffers from food shortages on a regular basis as result of climate extremes such as drought (Zambia, Zimbabwe) and floods (Mozambique) which affect agricultural production. Most countries will not be able to meet the MDG 1 on reducing poverty and hunger by 2015.

The main driving force behind food insecurity in the region is water scarcity. Water scarcity, either physical or economic, is predominantly due to climate change, increasing population, increasing water demand, changes in land use leading to water availability problems, deteriorating water quality, and changing dietary habits resulting in a demand for more water.

Due to the fact that the bulk of agriculture is rainfed in the region, opportunities exist to improve food production through attention to practices that improve agricultural water management, increase water productivity and increase the resilience of the agricultural production systems. Practices such as rainwater harvesting, micro-agricultural water management and dry spell mitigation all work towards improving water productivity and building resilience. Once agricultural systems have improved water productivity and are resilient, they are able to produce food for the population under even difficult conditions. Policies and investments should be directed towards such efforts.

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By 2050 the world’s population could exceed 9 billion, a 50% increase compared to 2000. Food production will therefore have to increase globally by 70%, perhaps by 100% in developing countries. Producing more food will require more water, yet water shortages and water scarcity are already a problem in many parts of the world. Water use has been growing globally at more than twice the rate of population increase in the last century and an increasing number of regions are reaching the limit at which reliable water services can be delivered. By 2020, water use is expected to increase by 40%, and 17% more water will be required for food production to meet the needs of the growing population.

With contributions from international experts, Water Management for Global Food Security demonstrates how water supplies and food security issues vary widely between and within countries, and what can be done to boost food production, so as to reduce poverty and malnutrition among the world’s most vulnerable people.

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