

CGIAR Challenge Program on Water and Food

Changing the way we manage water for food, livelihoods, health and the environment



Baseline 2004

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Foreward

A key feature of the CGIAR Challenge Program on Water and Food (CPWF) is to add value to project results by synthesizing these and other relevant research findings so as to develop a comprehensive and credible knowledge base on increasing water productivity in ways that contribute to poverty alleviation and to enhancing food, health and environmental security. This knowledge expands and changes with time, and CPWF's synthesis research aims to keep up with these changes.

CPWF deals with complex, diverse and dynamic systems for which there are a growing number of stakeholders generating information. Synthesis research is needed to collate, unify, organize, extract and distill the ideas, information and knowledge and allow information users to gain insights and deduce principles, concepts and cause and effect relationships.

In order to identify emerging issues, draw attention to how CPWF addresses these issues, and illustrate what works and under what conditions, we first need to understand the baseline situation that exists in each of the nine benchmark basins, and in each of the five thematic areas.

This document draws together information from the Basin Profiles, prepared by Francis Gichuki and the CPWF basin coordinators, as well as information about the current state of research in water and food.

The Challenge Program wishes to acknowledge the significant input by members of its team into the writing, review, and revision of Baseline 2004, especially Larry Harrington who wrote in its entirety the present version, Francis Gichuki who prepared the original concept and draft document, Kim Geheb and Alain Vidal who made major contributions and revisions, and Reg McIntyre did detailed editing to bring the documents to publishable form.

Jonathan Woolley
CPWF Program Coordinator

Introduction

Poverty, food insecurity, hunger, malnutrition and disease form a deadly combination. Poverty is a cause of hunger (the very poor at times simply cannot afford to eat) while hunger is a cause of poverty (hunger robs people of the strength needed for work). Poverty and hunger increase susceptibility to disease (the malnourished are more vulnerable to infectious diseases and the poor often have no access to clean water). Disease, in its turn, can result in poverty and hunger.

These problems reinforce and feed on each other.

Water and food – the allocation and management of water resources and the availability of affordable food – are central to all of these problems. Plants and animals that provide food for humans need water to thrive. Water is also essential for rural and urban domestic use, industrial use, power generation, river transport, fish production, and the preservation of wildlife habitat and ecological processes.

As global population and urbanization increase, competition for water becomes more intense. Despite rapid urbanization, the rural population in the poorest countries will continue to increase – further increasing demand for water. Because most water resources in poor countries are used for agriculture, improvements in water productivity are becoming critically important.

The Challenge Program for Water and Food (CPWF) is contributing to the global fight against poverty, hunger, malnutrition, and disease by focusing on water productivity. To accomplish its goal, CPWF has chosen an integrated approach at the level of the river basin. CPWF cannot, however, work in all basins of the world, so nine basins have been selected that present diverse biophysical, socioeconomic, and institutional conditions. These are: the Andes system of basins, the Indo-Gangetic system of basins, and the Karkheh, Limpopo, Mekong, Nile, São Francisco, Volta, and the Yellow river basins.

CPWF benchmark basins

The actions of river basin inhabitants, taken together, affect the quantity and quality of water available at different points within the basin. The cumulative effects of people's actions on water resources increase as one moves downstream. When population pressure is low, the actions of upstream communities have limited downstream impact. As population pressure increases, competition for water and concerns about water quality become intense. It becomes increasingly important to find technical and institutional responses that can address these concerns.

The basin approach

How water is managed within a river basin can have huge effects on agricultural productivity and sustainability, livelihoods, income distribution, and the provision of environmental services. An integrated approach is essential to understand how these interact.

CPWF uses the river basin as a basic unit of analysis to achieve a holistic understanding of natural systems and how they interact with human activity:

Information on sources and uses of water, where sources include rainfall, surface water, groundwater and wastewater; and uses include rural and urban domestic, industrial, power generation, crop, livestock and fisheries production, and the preservation of wildlife habitat and ecological processes.

Upstream-downstream interactions, showing how agriculture affects downstream fisheries, wetlands and water-related environmental services.

"Water savings", identifying actions that truly improve water productivity at the basin level, rather than merely redistributing water resources among user groups.

Coordination of interventions

Systematic understanding of the basin-level effects of technology and policy interventions, to help identify interventions that improve water productivity and livelihoods for upstream water users; improve downstream water availability and quality; and "free up" agricultural water for other uses.

Planning of land and water use, so that decisions on institutional innovations, priorities for water resource development, and water allocation to different groups can be made in a fully informed way.

Cross-sectoral integration of policies and legal frameworks, allowing the effect on water management of macro, trade and other non-agricultural policies to be fully understood.

Better dialogue and communication

Improved dialogue between upstream and downstream communities, aimed at addressing contentious issues, including transboundary issues, arising from the management of shared water resources.

Integration of ideas and information from different disciplines and sources.

Improved communication across different management levels and scales.

Information sharing across basins, whereby lessons learned in one basin can be made available to people in other basins facing similar problems and concerns.

The selected basins

Nine river basins have been selected that present diverse biophysical, socioeconomic and institutional settings.

The selected basins cover Africa, Asia and Latin America. Some basins, such as the Volta or the Limpopo, combine intense poverty with extreme water scarcity in areas dominated by rainfed agriculture. Others, such as the Indus-Ganges or the Yellow River, feature huge populations of the very poor that are increasingly affected by water and land degradation – in both irrigated and rainfed areas. Together, these nine basins contain sufficient variety to represent most of the water and food challenges of developing countries. By focusing on these major basins, CPWF hopes to make significant contributions toward achieving the Millennium Development Goals.

Andes

The Andes basins represent countless small catchments whose waters flow from the Andes Mountains. From these catchments, a study region has been chosen consisting of ten sub-basins in Bolivia, Colombia, Ecuador, and Peru. The region is diverse in elevation, climate, agroecosystems, and social structures.

Poverty is widespread. Most farmers in the upper catchments are smallholders with less than 2 ha of land. Roads are hard to maintain and often dangerous, providing unreliable access to markets and services.

Land degradation is serious. A combination of widespread deforestation, steep hillsides, and

strong seasonal rainfall results in eroded soils and degraded water quality.

Water management is controversial. Important issues include conflicts over water supply to urban centers, use of water for irrigation, and the effect of water and land management in upper catchments on downstream water quality.

Water scarcity is common despite abundant rainfall because of inappropriate land use, over-extraction in the upper catchments, decreasing snowfalls in upper basins, and pollution of water resources by agriculture as well as by urban centers.



Area	3.8 million km ²
Population	89 million (2000)
Rural population	29% (2000)
Below poverty line	Bolivia: 14% Colombia: 14% Ecuador: 18% Peru: 16%
Climate	Varies from humid and tropical to cold and semiarid
Annual precipitation	1,835 mm average 400 – 2200 mm range
Total renewable water resources	5,100 km ³ /yr (total)
Water use by sector	Agriculture: 73% Domestic consumption: 21% Industry: 6%
Cultivated land	3.7% of total
Irrigated	30,870 km ²
Rainfed	108,750 km ²

Indus-Ganges

This basin is large and productive, and is home to nearly three quarters of a billion people. It extends over 3200 km from the mouth of the Ganges to the Indus, covering large areas of Bangladesh, India, Nepal and Pakistan, and containing 114million ha of cropped area.

Poverty and food security are critically important. The history of the Indus/Ganges is one of droughts, floods, and famine. The basin supports some of the highest rural population densities in the world. Green Revolution technologies and investments in irrigation and related infrastructure have helped produce a food surplus. Future food security could be threatened, however, by a combination of land and water degradation, stagnating productivity, reduced harvested area, and relentlessly increasing demand. Thirty percent of basin inhabitants are extremely poor.

Groundwater use is not sustainable. Past development of tubewell irrigation was an important factor in increasing food production and reducing poverty. Now, however, the basin is being confronted with major groundwater management challenges: over-exploitation of groundwater and declining water tables in the drier Indus part of the Basin, waterlogging, and secondary salinization in irrigation command areas, and pollution.

Major opportunities exist, however, to substantially improve land and water productivity, including better governance. In the lower Ganges, groundwater resources are under-used, not over-exploited. And a new wave of resource-conserving technologies such as zero tillage is already being adopted by farmers. Continued research is needed to further develop the high potential of this basin.



Area	2.25 million kms
Population (2001)	747 million
Rural population (2001)	India: 75% Bangladesh: 80% Nepal: 86% Pakistan: 68%
Below poverty line (2000)	30%
Mean annual rainfall	400 - 1,254 mm
Climate	Range of arid, semi-arid, humid tropical, temperate
Total net cropped area	114 million ha
Annual water use by sector (1995)	Agriculture: 91% Domestic: 8% Industry: 1%
Institutional arrangements for managing water	State/Provincial governments and corporations/boards.

Karkheh

This Iran basin is not large. It is comparable, however, to many other basins with problems of rural poverty, land degradation, low productivity of water in agriculture, a dry climate, and growing upstream-downstream competition for water.

Over the past 20 years more than half the basin's rural families have migrated to towns and cities in search of better livelihoods. Rural poverty has made wise stewardship of the land in this naturally harsh environment all the more difficult.

Catchment degradation and soil erosion affect 90% of the upper watershed's rangelands and 70 % of its forests. High rainfall intensities, steep

slopes and poor land management in the upper watersheds result in high runoff and soil erosion. Downstream, river-borne sediment is starting to clog the newly built Karkheh Reservoir.

Irrigation systems are faltering, crop yields are well below potential, and agrochemicals are polluting groundwater.

The Hawizeh marsh, a remainder of the famous Mesopotamian Marshlands and the habitat for several endangered species, is fed by the Karkheh River. At present, only 10% of the original wetland area remains. Improved water productivity in other parts of the basin is essential to preserve this marshland.



Area	50,764 km ₂
Population	approximately 4 million
Rural population	67%
Rural per capita annual income from agriculture	US\$230
Rainfall	Ranges from 150 mm in the south to 750 mm in the north
Total developed water resources	Over 8 billion m ₃ (after completion of Karkheh dam)
Irrigation water consumption	3.9 billion m ₃ /year (more than 60% surface water)
Groundwater consumption and uses	1.65 billion m ₃ /year Agriculture: 87% Domestic consumption: 12%; Industry: 1%
Irrigated area	1,100 km ₂ , with planned expansion to 3,400 km ₂
Major crops and percent of cultivated area	Wheat and barley: 76% Pulses: 23%
Institutional arrangements for managing water	Ministry of Power, responsible for water development and allocation

Limpopo

The basin drains the highland areas of Botswana, South Africa, and Zimbabwe and the lowland areas of Mozambique.

Many communities have an average annual per capita income of less than US\$200. Farming represents less than 50% of household income.

About 1 million people rely on food aid, and starvation occurs with alarming frequency.

Farming is risky. Basin rains are intense and unreliable. Late rains and recurring dry periods

during the growing season are common.

Competition for water among countries, sectors, and communities is increasing. There are rising demands from urban and mining water users –and also from beneficiaries of new small irrigation projects.

Opportunities for progress include improving crop productivity without increasing water use, by introducing drought-resistant varieties and suitable land management practices, introducing appropriate water policies and governance, and adopting a basin approach to water management.



Area	412,938 km ²
Population	14 million
Rural population	57%
Below poverty line	40%
Mean annual rainfall	530 mm (range 200 - 1,200 mm)
Climate	Tropical dry savanna and hot dry steppe to warm and cool temperate
Net cropped area	5% (approx.)
Net irrigated area	244,000 ha
Land use	Pasture: 1.78 million ha Forests: 455,000 ha Crops: 234,000 ha
Institutional arrangement for managing water	Limpopo River Basin Commission
Environmental conservation areas	Two Ramsar sites, two large and several smaller game parks

Mekong

This basin extends from the Tibetan Plateau to the South China Sea and covers parts of six countries: China, Cambodia, Lao PDR, Myanmar, Thailand, and Vietnam. Much of the basin receives abundant rainfall.

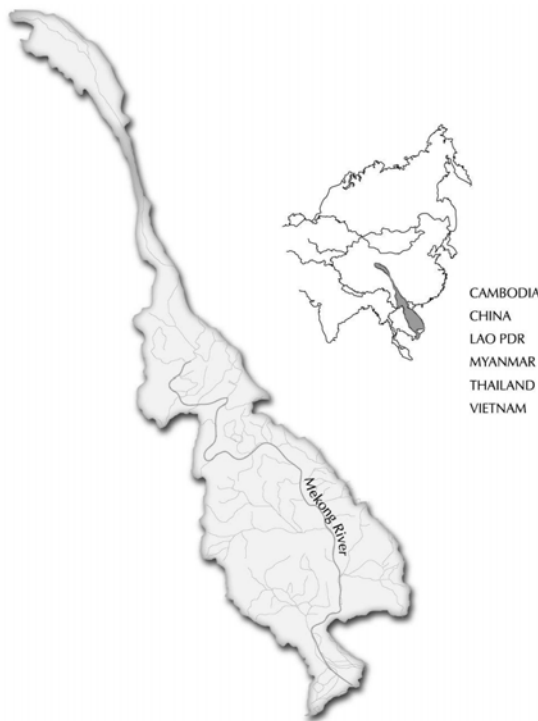
Competition for water among countries, communities, and sectors is a major issue. The basin's inhabitants rely heavily on the Mekong for agriculture and fisheries, but there are growing demands that the river be used more for transportation and for hydropower generation. River traffic has expanded in response to the growing trade. Dams on Mekong tributaries and on the mainstream in China are producing 1,600

megawatts of electricity but less than 5% of the total hydropower production capacity in the lower Mekong basin has been developed.

Downstream fisheries are threatened. Fishing is a major source of income for poor people in the basin.

Agricultural water productivity is low. New technologies can be introduced to improve rice yields without using more water.

Integrated basin management is considered necessary to address food insecurity, rural poverty, environmental degradation, threats to biodiversity, and tensions among multiple users.



Area (MRB)	795,000 km ²
Component countries and share of MRB area	Cambodia: 20% China (Yunnan Province): 21% Lao PDR: 25% Myanmar: 3% Thailand: 23% Vietnam: 8%
Population (MRB)	58.7 million
Rural population	90%
Rainfall	Korat Plateau, 1,000-1,600 mm; Northern Highlands; 2,000-2,800 mm; Eastern Highlands, 2,000-3,000 mm
Climate	Tropical to cool temperate
Water used for agriculture (LMB 2000)	Cambodia: 97% Lao PDR: 90% Thailand: 96% Vietnam: 68%
Cropped area (LMB 2000)	Irrigated: 3.28 million ha Rainfed (MRB): 11.22 million ha

Nile

The Nile basin covers parts of 10 countries: Burundi, D.R. Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda. Basin water resources are fundamental to the livelihoods of nearly 160 million people.

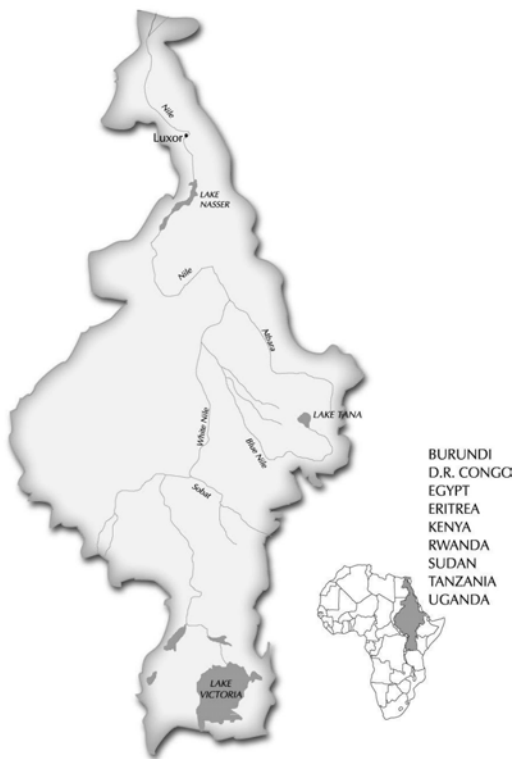
Poverty is pervasive. Five of the world's 10 poorest countries lie in the basin, and about 80 million of its inhabitants earn less than US\$1 per day.

Land degradation and water pollution are fundamental problems. Deforestation and cultivation of steep slopes in upper catchments have led to heavy soil erosion, loss of biodiversity, and

sedimentation of lakes and reservoirs. Water pollution by agrochemicals, sewage, and industrial waste is a growing concern.

Water productivity in agriculture is low. Rainfed and irrigated crop yields are less than 20% of the potential, and water is the main constraint. The high costs to develop irrigation make this an unrealistic option, so improvements in water productivity in rainfed agriculture are essential.

The trans-boundary nature of the Nile basin is an important factor. The Nile Basin Initiative and similar arrangements form a sound basis for international cooperation in water management.



Area	3.1 million km ² , including 81,500 km ² of lakes and 70,000 km ² of swamp
Population	160 million, or 57% of the population of the basins riparian countries
Rural population	Burundi: 93% D.R. Congo: 71% Egypt: 57% Ethiopia: 85% Kenya: 71% Rwanda: 94% Sudan: 67% Tanzania: 76% Uganda: 88% Eritrea: 85%
Below the poverty line	Approximately 50%
Climate	Highly variable
Primary water uses	Irrigation, industry, domestic supply, hydropower, navigation
Irrigated area	5.5 m ha, potential for 10.2 million ha
Protected areas	More than 100

São Francisco

The basin covers a large portion of the area known as the “Drought Polygon of Brazil.”

Problems related to urbanization and industrialization include surface or open cast mining for metals and minerals, agroindustrial product processing, and residential area expansion without adequate wastewater treatment and solid waste management. The region’s traditional fishery is in decline, and reports of conflicts related to competing uses of water are becoming more frequent.

Land degradation problems include draining coastal wetlands, and the consequences of converting land from forest to agriculture. Industrial farming operations and land-clearing practices have disturbed large areas of land and have resulted in the deforestation of riverbanks and uplands. Land degradation is undermining the region’s rich biodiversity of both plants and animals, adversely affecting agricultural production and drastically reducing water flows during dry periods.



Area	640,000 km ²
Population	16 million
Urban population	Average, 77% (49% in lower basin, 96% upper basin)
Mean annual rainfall	1,000 – 2,000 mm (upper basin) and 350 – 800 mm (lower-middle basin)
Annual evapotranspiration	1,000 – 1,600 mm
Climate	Mix of semi-arid and savanna-like conditions
Irrigated area	333,000 ha (fruit trees, horticulture and some soybean)
Rainfed agriculture	Mostly annual crops (maize, beans, rice), cassava and pasture
Basin water demand	7.06 billion m ³ /year Irrigation, 71.4% Urban supply, 12.5% Livestock, 3.1% Industry, 13%

Volta

The Volta basin is 1,400 km long and straddles six countries, although most of the land area is in Ghana and Burkina Faso. The basin suffers from extreme poverty, a growing population, and a looming water crisis.

The Volta basin is one of the poorest regions of the world. More than 60% of the people in Burkina Faso live on less than US\$1 per day. Other countries in the basin are not much better off.

Food security is threatened because population is expected to more than double over the next 25 years. To meet expanding food requirements, agricultural production will need to rise rapidly. Achieving such targets will depend heavily on the availability of water resources.

Competition for water is getting stronger. Dams and reservoirs have been built throughout the basin

to serve agricultural, domestic, and energy needs although in most years, rivers in the Volta basin only flow for three or four months. Groundwater is neither abundant nor easily accessible. Under extreme drought conditions, deciding how much water should flow through the dams to generate electricity, at the expense of upstream needs, can be a matter of life and death. There are no formal water allocation arrangements among the basin's countries.

Growing more food with less water must be part of the solution. This includes developing crop varieties for specific growing environments; designing on-farm water harvesting methods to cope with dry periods and erratic rainfall; developing integrated crop-tree-livestock systems that conserve water and maximize yield, and developing highly efficient small irrigation schemes in valleys and floodplains.



Area	400,000 km ² , mostly in Burkina Faso and Ghana
Population	18.6 million (2000)
Rural population	Range of 64% - 88%
Below the poverty line	Burkina Faso: 45% (1994) Ghana: 45% (1999)
Annual rainfall	From 1,600 mm in the southeastern to 400 mm in the north
Climate	Humid southern zone with two distinct rainy seasons; tropical transition zone; tropical dry northern zone with one rainy season peaking in August
Total annual water demand	1.7 billion m ³
Cropped area irrigated	Less than 1%

Yellow

The Yellow River basin in China originates in the mountains of eastern Tibet and then passes through eight provinces and the Inner-Mongolia Autonomous Region before emptying into the sea. Development of irrigation, power generation, and flood control contributed to economic growth, but negative effects are now being felt.

Soil erosion and siltation are major problems. The Loess Plateau is considered the world's most erodible land. In the lower Yellow River, sediment transported from the middle reaches begins to settle as the river spills onto the flat North China Plain. To stabilize the channel, levees have been constructed over many years, which has created a suspended river, in which the channel bottom is above ground level.



Water scarcity and competition for water is intensifying, and consumption has soared while rainfall has been below average. As a result, the lower Yellow River has frequently dried up. Major reductions in base flow have severely affected household and industrial water supply, irrigation, and power generation. They have also resulted in deterioration of delta ecosystems and coastal fisheries, and in siltation of the river channel, greatly reducing flood conveyance capacity.

Flooding occurs frequently and with devastating impact. The Yellow River also suffers from huge pollution problems. An estimated 4 billion cubic meters of effluent is discharged annually into the river without effective treatment each year.

Area	795,000 km ²
Population	189 million, including 87 million in the flood-prone zone (2000)
Rural population	73.6% (2000)
Number of people below poverty line	21.3 million
Mean annual rainfall	452 mm
Climate	Arid, semi-arid
Annual average runoff	58 billion m ³
Groundwater resources	11 billion m ³
Water demand (2010 projection)	52 billion m ³
Water supply (2010 projection)	48 billion m ³ (normal year), 42 billion m ³ (medium dry year)
Minimum water needed for environment	5 billion m ³ in the dry season, plus 14 billion m ³ in the flood season for sediment flushing

The challenges: Poverty, hunger and disease

Demographics

Poverty, food insecurity, disease and environmental degradation are problems of global consequence. These problems arise from a complex process involving numerous factors, some of them beyond the scope of water resource management or agricultural development.

One fundamental factor, however, shapes all four of these problems and has strong water-related implications as well. That factor is demographic change. The pace and structure of population growth and urbanization have direct effects on agricultural, urban and industrial water requirements. The level of water resources available, how these are allocated and how much water remains for agricultural production, increasingly will be affected by population growth. Rapid rural population growth, along with inequitable allocation or inefficient use of water, contributes to water scarcity in agriculture. In some instances this may increase food insecurity.

The swift process of urbanization unfolding in numerous countries is likely to have many effects on agriculture, including increased demand for high value crops; increased urban water demand; and increased wastewater flow into rivers or groundwater and urban encroachment on prime agricultural lands. Urbanization reshapes the structure of demand for food, resulting in reduced food demand for coarse grains, roots and tubers, and increased demand for cereals requiring less preparation, particularly wheat. Demand also increases for fruits, vegetables and livestock products – further expanding requirements for agricultural water.

Rapid population growth and high dependency ratios indicate the importance of employment generation for that time in the near future when today's youth enter the work force. Despite rapid urbanization, agriculture will continue to be an important source of employment in many benchmark basin countries, especially the poorest.

Demographic change will have a strong effect on water availability and use. These, in turn, will influence the extent to which efforts to solve development problems – to reduce poverty, improve food security, foster enhanced health and reduce environmental degradation – can be successful.

Poverty

Poverty usually has many causes, among them: slow economic growth; the presence of debilitating diseases; inadequate availability of water and other resources; the presence of civil conflict; inequitable distribution or inefficient use of resources; lack of opportunities for rural to urban migration; inadequate investments in education; poor infrastructure; lack of employment-generating, productivity-enhancing technical change in agriculture; high levels of risk in agricultural production; inappropriate macroeconomic or sector policies; and substandard governance.

Interventions to improve water or agroecosystem productivity are often necessary – but may not be sufficient – for success in poverty reduction. When assessing the impacts on poverty of research on water and food, this broader context must be kept in mind.

Having said this, it has long been known that productivity-enhancing employment-generating technical change in agriculture can, under some conditions, be a powerful way to foster widespread economic growth (Mellor, 1966). This occurs through direct mechanisms (higher rural farm incomes earned by a larger number of more productive people) and indirect mechanisms (the growth of a non-farm service sector catering to a wealthier farm population). This process unfolds most rapidly and is most effective when water and land resources are distributed in a reasonably equitable fashion. Furthermore, rapid economic growth and higher incomes (along with investments in health care and women's education) are important factors in slowing

population growth. Thus, the process comes full circle (Pinstrip-Andersen, Pandya-Lorch, and Rosegrant, 1999; Swaminathan, 1995; Poleman, 1989).

Howsoever desirable this process may be, water scarcity can bring it to a halt. Improvements in agricultural water productivity often will be needed for this particular engine of growth – productivity-enhancing, employment-generating technical change in agriculture – to get moving.

Food security and hunger

The problems of poverty, food insecurity, hunger, malnutrition and disease are all inter-related. The very poor frequently and repeatedly do not have enough to eat. Unable to purchase food, they may actually starve in the midst of a food surplus. Similarly, hungry and malnourished adults are unable to work as hard as their relatively well-fed neighbors. Hunger robs people of the strength to work productively.

Micronutrient malnutrition or “hidden hunger” is estimated to affect more than 2 billion people. Iron deficiency increases the risk of death from malaria while Vitamin A deficiency impairs the immune system. The malnourished are more likely to suffer from cancerous lesions associated with arsenic-tainted groundwater. Children are especially vulnerable to hunger. Malnutrition among pre-school children leads to permanent mental and physical stunting, illness – and sometimes death. It impedes economic growth and transmits poverty and ill health across generations.

Finally, disease can cause food insecurity and poverty. HIV/AIDS reduces peoples’ ability to acquire food, turns millions of children into orphans, and reduces the availability of productive farm labor. African preschoolers account for 90% of malaria deaths and, because malaria often strikes during harvest time, it can undermine food security (IFPRI, 2005).

Given the strong relationship among the problems of poverty, hunger and disease, it would be best if they could all be addressed and solved together. Improved water productivity in agriculture will often be an essential part of poverty reduction and improved food security.

Disease

The relationship among hunger, disease, and access to clean water is exceptionally close. Lack of agricultural water can result in inadequate food production, in some instances leading to hunger and malnutrition and ultimately to increased vulnerability to disease. Lack of access to clean water is also directly associated with several important diseases, among them (WHO, 2004):

Diarrhea (about 1.8m people die each year from diarrhea-related diseases; 90% are children under 5, mostly in developing countries; 88% of diarrhea problems are caused by unsafe water supply and inadequate sanitation).

Malaria (about 1.3m people die each year from malaria, once again largely children in developing countries, especially sub-Saharan Africa; dams and water resource development sometimes exacerbate the problem).

Schistosomiasis (6 million people are visually impaired by trachoma; this disease is related to lack of face washing, often due to absence of nearby sources of safe water).

Hepatitis A (about 1.5m cases of clinical hepatitis A occur each year).

Arsenic poisoning (In Bangladesh, between 28 and 35 million people consume drinking water with elevated levels of arsenic; 1.5m of them develop skin lesions related to arsenic poisoning).

For its part, malnutrition has been called “globally the most important risk actor for illness and death, with hundreds of millions of pregnant women and young children particularly affected”.

The resources: Land and water

Agriculture is more likely to make a major contribution to defeating the deadly combination of poverty, food insecurity, hunger, malnutrition and disease, when the following conditions hold: land and water resources are equitably distributed; production practices for crops, livestock, and fish enhance productivity and create employment; and steps are taken to conserve and improve land and water quality, and to preserve environmental and ecological services.

These conditions often are not met. The amount and quality of land available for agriculture is increasingly limited by erosion, salinity, waterlogging, reduced investment in irrigation, and urban encroachment. Water-related problems in agriculture include droughts, floods, groundwater depletion and water pollution. At the same time, the quality and quantity of water available for agriculture is being limited by the need to allocate more water to urban and industrial use.

Land

At the global level, land per se does not limit agricultural production. The problem lies in the distribution and quality of land resources. Taking account of land quality categories and their respective productivity, it is estimated that all agricultural lands combined, if managed under low-input conditions, could support a global population of about 6.2 billion. With medium input technologies, this increases to about 8.7 billion persons (Eswaran et al 1999).

The area and quality of agricultural lands change over time, influenced by land management

A closer look – the Yellow River basin

All CPWF benchmark basins suffer from soil erosion, but the problem is particularly acute in the Yellow River basin. The Loess Plateau, for example, is widely considered to be the world's most erodible land. Jiang Deqi et al. (1981) estimated that erosion rates may be as high as 18,000 tons per square kilometer in some catchments. Erosion from the Loess Plateau is one reason why the Yellow River has such a massive concentration of sediment, 1.6 billion tons per year. The average sediment concentration is 35 kg/m³, but can reach 970 kg/m³.

When fine sediment is deposited in fields, it can improve soil fertility, but sediments deposited in irrigation and drainage canals gradually become obstructions. Sediments deposited in the downstream river channel raise the level of the river bottom, requiring further construction or raising of levees.

The Chinese Government has implemented a large-scale re-vegetation and soil and water conservation program called the "Clean River: Green Hills," in an attempt reduce soil erosion and improve water quality. Soil and water conservation has increased grain production and reduced sediment yield. At current rates, however, it will take 100 years to cover all areas.

practices. Soils erode and land is abandoned. Waterlogged areas expand. Lands become saline – or are reclaimed. Soil fertility is lost – or improved. Forest areas are converted to cropland, and then claimed for urban expansion. With population growth and urbanization, the pace of change quickens.

A closer look – the Indus-Ganges basin

Many irrigated areas have problems of irrigation-induced waterlogging and salinity, but the problem is particularly acute in the western, drier transects of the Indo-Gangetic basin. In the Indian Punjab about 60,000 ha are affected by salinity and alkalinity. In Haryana state, large areas are affected by rising water tables that at times break the surface. In the arid to semi-arid climate, evaporation is swift and salt concentrations in waterlogged areas increase.

Farmers use lower levels of external inputs in salt-affected areas, thus further reducing land productivity (Singh and Singh, 1995). Land productivity is further reduced when salinity exacerbates the effects of micronutrient deficiencies (Sadana, 1990). Measurable crop yield reductions associated with soil salinity have been found at the regional level in northern China (Huang and Rozelle, 1995).

In Pakistan, farmers tend to minimize the amount of groundwater pumped (to reduce costs of pumping), whereby leaching requirements are not met and secondary soil salinity emerges.

Changes in irrigated area

Continued expansion in irrigated area is likely to be slow at best, and increasingly expensive. Real costs of new irrigation in India, Pakistan and India at least doubled between 1970 and 1990. In Africa, irrigation

construction costs are even higher than in Asia. And these do not take account of undesirable environmental and human re-settlement costs. Environmental consequences can include loss of habitat, loss of species, siltation, salinization, deforestation, changes in water quality, depleted fish stocks, effects on wetlands, and reduction in silt carried out to sea (Rosegrant et al., 2002).

Land resources in benchmark basins

Several indicators regarding land resources are shown in Table 1 for selected countries in benchmark basins. For each country, estimates are provided for the proportion of land under arable and permanent cropland, of land under permanent pasture, and of land under forest. Estimates are given for two different dates, to allow some comparison of changes over time. Then, the proportion of agricultural land that is irrigated is given for the year 2002.

With few exceptions, the proportion of land under arable and permanent cropland continued to expand (1992 to 2002) in all basins. Typically, the rate of expansion was imperceptibly slow but in a few cases it was rapid.

The large proportion of agricultural land that is irrigated in the Asian basins is shown in stark contrast to the near absence of irrigation in sub-Saharan Africa.

Table 1. Land resources indicators in benchmark basins.

	Percent land area arable and permanent cropland (2002)	Percent land area arable and permanent cropland (1992)	Percent land area permanent pasture (2002)	Percent land area permanent pasture (1992)	Percent land area forest (> 10% tree cover) (2000)	Percent land area forest (> 10% tree cover) (1990)	Percent agricultural land irrigated (2002)
Andean							
Bolivia	3	2	31	31	48	50	4
Ecuador	8	7	23	22	48	50	29
Indo-Gangetic							
Bangladesh	65	64	5	5	9	8	54
India	57	57	4	4	20	19	34
Pakistan	29	27	6	6	3	3	81
Karkheh							
Iran	10	11	27	27	4	4	44
Limpopo							
Mozambique	6	5	56	56	38	39	2
Zimbabwe	9	8	44	44	49	57	4
Mekong							
Cambodia	22	22	8	8	52	55	7
Lao PDR	4	4	4	3	53	55	18
Thailand	38	40	2	2	29	31	26
Vietnam	27	21	2	1	30	28	34
Nile							
Ethiopia	11	10	20	41	5	4	2
Kenya	9	8	37	37	29	31	2
Uganda	37	35	26	26	17	21	< 1
São Francisco							
Brazil	8	7	23	22	66	64	4
Volta							
Burkina Faso	16	13	22	22	26	26	1
Ghana	28	19	37	37	27	32	<1
Yellow River							
China	17	14	43	43	17	15	36

Source: World Resources Institute, 2005.

Water

Fresh water is distributed unevenly across the globe, with per capita availability highest in the Americas and lowest in Africa and Asia. How these water resources are used (especially renewable freshwater resources) can make the difference between well-being and poverty.

Human intervention in water management affects the environment. Rivers stop flowing, seawater intrudes into freshwater aquifers and biodiversity is lost. Agriculture alters the hydrologic regime through the construction of reservoirs and drainage of wetland, affecting migratory aquatic species.

Alternative water resources have been developed through desalination, urban or agricultural wastewater reuse, and brackish water reuse. In some cases, they may represent a cost-effective alternative to conventional water resources, but could also pose a risk to health and food product marketing.

Drought

For many benchmark basin countries, the economic shocks from drought can be wide-ranging and devastating. These can include a decline in crop and livestock production, reductions in hydroelectric power generation and water-intensive industrial processing, and sometimes a shortage of water for domestic use. These, in turn, lead to lower domestic industrial output, and reduced employment, demand, expenditure, and savings. The effects of drought on agriculture depend on its frequency, its duration, its timing with respect to the agricultural cycle, and the capacity of soils to conserve moisture.

Farmers in drought-prone areas often have elaborate coping strategies, but these can fail when drought is prolonged.

Flooding

Floods are a recurring event in many benchmark basins. Human factors that contribute to flooding

include upstream deforestation, land degradation, reclamation of wetlands, rapid urban expansion, modifications to river channels. Climate change, whether affected by human activity or not, also increases the severity and the frequency of extreme floods.

In the Mekong basin severe floods occurred in 1961, 1966, 1978, 1984, 1991, 1994 - 1996, 2000, and 2001. The economic and social costs were severe: fatalities, evacuations, damage to infrastructure, and loss of agricultural production. A sizeable area in the eastern Indo-Gangetic plains remains flooded during the monsoon and remains wet for a long time due to poor drainage. A major cause of increased flooding in Bihar, West Bengal, and Bangladesh is thought to be deforestation in upstream catchments, reducing their capacity to absorb monsoon rains.

Though floods can be devastating to communities, they can generate considerable environmental benefits, including soil fertility enhancement in floodplains, improvements in the ecological health of river systems, river channel maintenance through flushing of deposited material, and recuperation of vegetation, fish and other wildlife.

Water pollution

Agricultural activities are at times a major source of water pollution. Pollutants related to agriculture include sediments, nutrients (mainly nitrogen and phosphorus), pesticides, and bacteria and salts. The presence of these pollutants can make water unfit for other uses.

In the São Francisco basin, for example, natural river flows have been altered, affecting the deposition of sediments, nutrients, organic pollutants, heavy metals, and other contaminants. Significant modifications in freshwater, estuarine and marine fauna and flora have occurred.

In the Yellow River basin, degradation of water quality has become an increasingly visible problem. An estimated 4 billion m³ of untreated effluent found its way into the river in 2000, more than twice

as much as in the 1980s. Despite strong public demand to solve this problem, it may be too expensive to treat all wastewater.

Groundwater mining

Groundwater extraction that exceeds recharge, and the corresponding decline in groundwater levels, have the following negative impacts: increased costs of pumping, land surface subsidence, intergenerational inequity – loss of resource, degradation of surface ecosystems that depend on groundwater, and salt intrusion. As groundwater levels sink, the relatively wealthy can afford to deepen their wells; the poor often cannot, thus forcing their departure from irrigated agriculture and deeper into the poverty trap.

Over-withdrawal of groundwater resources and aquifer depletion occurs in many of the benchmark basins:

In Northern China, groundwater tables are dropping at unprecedented rates. In the Beijing area, for example, the water table has dropped 45 m since the 1950s (Brown and Mitchell, 1997).

In several important production areas in India, water tables have been falling at annual average rates of 2-3 m due to the growing number of irrigation wells. Some analysts predict that 25% of India's harvest may be placed at risk in the coming years (Gleick, 2000).

Fossil aquifers, which are typically deep underground and receive little or no recharge, are being utilized for irrigation in some of the arid regions of the world. Pumping of fossil water constitutes water mining, one-time extractions from a depletable reserve. Egypt is irrigating 17,000 ha of cropland from fossil aquifers (Abu-Zeid, 1992).

Effective institutional, legal, regulatory and economic instruments for effective groundwater management are known. These work through demand regulation and supply augmentation. However, their success has for the most part only been demonstrated in industrialized countries, and has involved relatively small numbers of large farming enterprises. Experience in developing countries has been less favorable. The barriers to adoption of known measures include:

The numbers of farmers and wells involved, and the corresponding difficulty in enforcing regulations.

The absence of policies that restrict groundwater demand, for example energy pricing.

The value of groundwater as insurance against drought, which further increases its importance to farming communities.

The failure of large surface irrigation systems to deliver a reliable water service to farmers.

Drying rivers

Due to reduced runoff and increased water withdrawal and depletion, some rivers in benchmark basins no longer reach the sea.

Between 1972 and 1998, the Yellow River dried up 21 times. During the 1990s, the river dried up *every* year and the length of the dry river section increased over time. By 1997, there was no flow out of the basin for 226 days and the dry river section extended as far as Kaifeng, about 600 km from the sea. In 1999, the government of China strengthened the "Water Allocation Program", which specifies water withdrawal quotas for provinces along the basin. Since then, the river no longer totally dries up. However, water flow for ecological uses, especially for sediment flushing, sustaining wetland ecosystems and prevention of seawater intrusion, is still far below the required amounts.

Seawater intrusion

Activities that decrease groundwater recharge, such as river diversion or flood prevention works, can affect the dynamic balance between the saltwater and freshwater interface. Changes in the quantity, timing, or direction of flows can affect surface and sub-surface salinity in the coastal zone.

In the Mekong Delta, for example, salinity is caused by the intrusion of seawater. This is a concern to farmers near the mouth of the river, where about 750,000 ha are affected by the entry of seawater during the dry season. Efforts to block the entrance of seawater lead to other problems. Water stagnates and may result in fish-killing algae

blooms. Water polluted with human waste, pesticides and other substances is not flushed into the sea. But if river water is used to flush away intruding seawater, there is less available for irrigation.

Loss of biodiversity

There has been a good deal of success in getting water to people and farms where and when needed but less success in adequately protecting the fundamental ecological functions of rivers and aquatic systems. The consequences of water development on aquatic ecosystems are now being seen: degraded river deltas, species on the brink of extinction, shrinking inland lakes and disappearing wetlands.

The Andes basin contains areas of very high biodiversity which are under threat from land use and climate change. Because the Inter-Andean valleys are relatively hospitable to human habitation, they have also been most affected by biodiversity loss.

The construction of the High Aswan Dam across the Nile River greatly altered the river system and its aquatic ecosystem. Out of the 47 commercial fish species in the Nile river prior to the dam construction, only 17 were still harvested a decade after the construction.

The western half of the Ganges Delta contains the Sunderbans, the largest single block of natural mangrove forest in the world, with dynamic and highly diverse plant and animal communities. At present, the Sunderbans are under considerable threat from a reduced water flow caused by upstream water extraction.

In the Yellow river basin, years of reduced water flow and has greatly damaged the estuary environment. The shoreline has retreated, salt water has intruded, and wetland area has shrunk by 70%. These wetlands are used by migrating birds, including many from protected species.

There is an urgent need to study the relationship between the river and its estuarine wetland, to

explore the pattern of wetland habitat evolution and ecological succession under the impact of water resources change, and to determine the minimum water requirement for the restoration of estuarine wetland ecosystems.

Water allocation change

Population growth and urbanization will result in a huge increase in the number of urban dwellers in developing countries. Urban domestic consumption of water will increase, possibly diverting water from agriculture.

As the structure of demand for food shifts toward water-intensive commodities, it may be difficult for rural areas to respond. One possibility might be to further develop peri-urban agriculture. Increasingly, we observe in and around cities farming systems that specialize in meeting urban food demand and dietary preferences, notably fresh vegetables and perishable goods.

Because only a small proportion of water inflow is actually evaporated by urban use, large amounts of urban return flows are generated. This wastewater is sometimes used in agriculture, either because it is nutrient-rich (thus reducing fertilizer use) or simply because it is the only reliable source of water. However, there are health risks for producers and consumers.

Water use conflicts

Projects aimed at providing water for agriculture can fuel tensions when they inadvertently reinforce existing inequalities. For example, resource-poor farmers, pastoralists and fishermen dependent on floodplains can be marginalized – and their livelihoods destroyed – when dams are constructed to provide irrigation water for upstream communities.

Most conflict over water has occurred between user groups or communities within countries. The potential for conflicts among countries is rising as downstream countries become vulnerable to

decisions by upstream countries to increase their water withdrawal. River basins most likely to be hot-spots for such hostility are those in which:

The river is shared by many countries.

Downstream states are highly dependent on the river water resources.

There is limited cooperation and equitable sharing of the water resources.

Downstream countries are militarily strong.

Egypt is vulnerable, with 97% of its surface water supplies flowing from upstream countries.

Ethiopia, which supplies 86% of the Nile's total flow, is now planning to expand its irrigated area, a move seen to threaten water availability for Egypt. The situation is complicated by the fact that the existing water allocation agreement was made without consultation with Ethiopia.

In the Ganges river basin, Bangladesh continues to suffer the vagaries of droughts and floods brought about by nature but worsened by the way upstream riparian states develop, use, and manage water and land resources.

The Agro Ecosystems: Crops, Livestock and Fisheries

The production of crops, livestock, and fish in basin countries continues to expand. With crop area stagnating and yield growth slowing, however, questions sometimes arise regarding the ability of production to keep up with demand. Livestock and fish production also face threats and constraints. Fortunately, opportunities exist to accelerate productivity and to foster development through improvements in water productivity.

Crops

Crop production is central to many of the issues already introduced: farm income, food security, health, and land and water use. Improvements in the productivity of agroecosystems, including crop water productivity, will be needed for success in reducing poverty and providing food for the future. Crop-livestock interactions are often very important. Livestock are often allowed to graze on, or are fed, crop residues. Farmyard manure then may be used to restore soil fertility or (in places where fuelwood is scarce) as fuel for cooking food. And, of course, animals serve as a power source for field cultivation, grain threshing, and other farm operations, and for transport. Finally, fish production is an important and valuable source of food for the poor in many benchmark basins.

Cropping systems in benchmark basins

Cropping systems vary across and within benchmark basins. Much of the Mekong basin, for example, is dominated by flooded rice systems, whether rainfed or irrigated, the latter more common near the Delta. Rice gives way to maize-based rainfed hillside systems (sometimes combined with tree crops) and slash-and-burn systems (in the more remote areas). These are very different from the drought-prone low productivity maize-legume-livestock systems found in the Limpopo basin.

The Nile basin has an especially large range of cropping systems, from the intensively farmed multiple-cropping irrigated systems of Egypt, to the rainfed teff and wheat small-grain systems in higher elevations in Ethiopia, and to maize-based hillside systems farther south. Even the Indo-Gangetic basin has an astonishing variety of cropping systems, with a complex and dynamic mosaic of rice, wheat, maize, oilseed, pulse, cotton, sugarcane, and mangos and other fruits and vegetables.

Poverty reduction and improved food security through better water productivity often depends on finding technical or institutional entry points to improve the management of particular cropping systems.

Cropping systems and employment

Crop production serves many purposes. Crops can provide food for the farm household, cash through the sale of crop commodities, fodder and feed for livestock, organic residues and green manures to enrich and protect soils, and employment for family members and landless laborers. At the national level, crops can be important sources of foreign exchange earnings.

Crop production within agroecosystems is often the single most important source of employment in rural areas. Incomes generated through crop production allow farmers and farm laborers to buy a wide range of goods and services. This generates further employment.

The very poor are often landless and survive by providing labor for others. Technical change in agriculture can help reduce poverty and improve food security and health when it expands employment opportunities and earning power for the landless.

Cropping systems, marketing margins, and food security

Marketing margins play a major role in determining the shape of an agroecosystem. They can also influence the extent to which a farming community is or is not food secure.

Marketing margins are simply the costs associated with taking something produced on the farm to sell in a market or, conversely, the costs of purchasing something in a market and conveying it back to the farm household. They include things like transport, storage and handling.

When marketing margins are high, farmers retain a relatively small proportion of earnings from the sale of a crop. The rest covers the marketing margin. Under these conditions, farmers have little incentive to produce crops for market sale. At the same time, it can become very expensive to buy food in the market for home consumption. The farmer needs to pay for the food – and also the high marketing margins needed to get that food home. Under these conditions, farmers have a large incentive to produce food for home consumption.

When marketing margins are low, the reverse is true. Farmers have a relatively large incentive to produce for cash sale and to purchase food in the market, as needed.

High marketing margins also discourage the use of external inputs. Once purchased in the market, it is expensive to convey these inputs back to the farm. Finally, high marketing margins are often related to food insecurity. When droughts or floods occur, or when for any reason the subsistence crop fails, the cost of obtaining food from alternative sources can be very high – sometimes too high for low-income households to afford. Hunger and malnutrition are quick to follow.

Finally, as urbanization and higher incomes shift the structure of food demand toward high-value commodities, diversified farms that enjoy low marketing margins will be in the best position to meet this demand. Such farms are unlikely to be owned by the very poor.

Crop production and agricultural productivity

Several indicators regarding crop production and agricultural productivity are shown in Table 2 for selected countries in benchmark basins. These indicators are not entirely satisfactory because basin boundaries and national boundaries do not coincide.

For each country, estimates are provided for an index of crop production for the time periods 1992-94 vs. 2002-04 (using 1999-2001 as a base period for the index), and for agriculture value added per worker for 1989-91 vs. 2001-03 (expressed in constant dollars for the year 2000).

Two things stand out: the swift growth in crop production in the Volta basin compared to that in the Limpopo and Nile, and the extraordinarily low agriculture value added per worker in the Limpopo, Nile, and Volta basins (and how little this has changed over the time period in question).

Trends in food grain area, yields, and production

The level of crop production is determined by harvested area and yield per unit area. It is estimated that cereal production in developing countries as a group will not keep pace with increases in demand.

Cereal harvested area will grow slowly in the coming decades (about 0.4 % annually). Although cereal area will continue to expand in sub-Saharan Africa (Rosegrant et al., 2005), it will actually decline in Asia. This is because a large share of the most suitable land is already being cropped, irrigation investment is expected to remain slow, soil degradation will take some lands out of production, and urbanization will lead to conversion of cropland to other uses.

When population growth is factored in, harvested area per capita will continue its inexorable downward trend. Harvested area per capita for cereals in developing countries has already fallen from 0.23 ha in 1950 to 0.12 ha in 1995.

There is, however, one more factor that will influence cereal harvested area - the projected continued slow decline in cereal prices. As the relative price of cereals to high-value crops declines, land use will shift away from cereals. These price movements simply reflect changes in the structure of food demand.

If increased production is not to come from expanded harvested area, then what about yields? As it happens, increases in cereal yields are slowing across all cereals and all regions – and have been doing so since the late 1980s. During 1982-95, cereal yields in

developing countries increased annually at the rate of 1.9 %. During 1995-05, the annual rate of yield increase is expected to slow to 1.2 %. Resource degradation and lack of water are two major reasons for this slowdown.

Ultimately, the discrepancy between rapid food demand increase and relatively slow production increase will be self-correcting. Either more food will be brought in from outside (commercial imports, food aid), or cereal prices will rise (exacerbating the plight of the urban and rural landless poor).

Table 2. Crop production indicators in selected benchmark basin countries.

	Crop production index 1992-94 (1999-2001=100)	Crop production index 2002-04 (1999-2001=100)	Agricultural productivity, agriculture value added per worker in 2000 \$ (1989-91)	Agricultural productivity agriculture value added per worker in 2000 \$ (2001-03)
Andean				
Bolivia	73	111	662	739
Ecuador	81	109	1969	
Indo-Gangetic				
Bangladesh	74	104	239	309
India	81	102	341	399
Pakistan	77	106	563	690
Karkheh				
Iran	82	111	1799	2354
Limpopo				
Mozambique	66	103	117	137
Zimbabwe	75	85	260	277
Mekong				
Cambodia	66	106		104
Lao PDR	64	120	351	459
Thailand	89	109	493	582
Vietnam	70	116	212	290
Nile				
Ethiopia	72	107		123
Kenya	80	99	184	148
Uganda	83	109	187	230
Sao Francisco				
Brazil	77	118	1658	3004
Volta				
Burkina Faso	79	119	140	163
Ghana	70	117	315	338
Yellow River				
China	68	113	242	357

Source: World Resources Institute, 2005

Livestock

In many basins, there has been a general shift toward intensive livestock production systems. Livestock production from intensive, industrial enterprises has grown twice as fast as from traditional mixed farming systems and more than six times faster than from grazing systems. This trend makes meat, milk, and other animal products more affordable for poor consumers – but, by depressing the price of animal products, may threaten the livelihoods of traditional livestock producers.

For traditional producers, livestock are more important than crops. Nomadic herders depend entirely on their cattle, goats, or sheep. Cattle in the Limpopo basin are stores of wealth that are sold as needed for cash – or in order to survive drought.

Livestock and crops

There are often strong interactions between livestock and crops. Livestock graze on crop residues and produce manure that may be used to restore soil fertility or (in places where fuelwood is scarce) as fuel for cooking food. Sometimes animals serve as a power source for farm operations, and for transport.

A closer look – the Nile basin

The Nile basin supports around 59 million total livestock units (TLU) with 60% in Sudan and Ethiopia. Livestock production systems make use of about 3.3 million km² of land. Of this, about 1.2 million km² (mostly in Sudan and Ethiopia) is devoted to livestock grazing on drylands, in systems where little or no crop production takes place. Other major systems feature mixed crop-livestock rainfed production (763,292 km² around Lake Victoria and in the Ethiopian highlands), mixed crop-livestock irrigated production (150,435 km² mostly along the Egyptian and Sudanese Nile), and urban and peri-urban livestock production (794 km²) (Thornton et al. 2002).

Livestock and the environment

Livestock production affects the environment. Intensive livestock production in upper catchments pollutes water later used by downstream consumers. Extensive cattle ranching in Latin America is often associated with the rapid destruction of valuable tropical forests. Frequently, land degradation and soil erosion is traced to overgrazing, especially when pasture is managed as common property.

Livestock and land use

In some basin countries, a large proportion of the land is used for permanent pasture. The huge contrast between the Indo-Gangetic and Mekong basins (with very small areas under permanent pasture) and the Limpopo and Nile basins (where permanent pasture is a major land use) is shown in Table 1. Caution is needed in making comparisons. Indicators are not entirely satisfactory because basin boundaries and national boundaries do not coincide. This probably accounts for the apparent anomaly concerning China – permanent

A closer look – the Mekong basin

Livestock production increased substantially during the 1990s in Cambodia, Viet Nam and Lao PDR. The increases are probably due to the impact of economic reforms in Vietnam and Lao PDR and increasing political stability in rural areas in Cambodia. Livestock production in Thailand, after an initial 20 % increase in the early 1990s, remained reasonably constant for the rest of the decade.

There is significant opportunity to increase livestock production, particularly in Lao PDR, where large areas of potential pasture land are available, and the government is actively encouraging upland households to switch to animal husbandry as an alternative to shifting cultivation. Increasing the capacity of livestock production, however, is constrained by low-quality forage and fodder, inadequate animal health services, and low productivity of the native stock.

Table 3. Livestock production indices for benchmark basin countries.

	Livestock production index 1992-94 (1999 - 2001 = 100)	Livestock production index 2002-04 (1999 - 2001 = 100)	Change
Andean			
Bolivia	78	108	30
Ecuador	70	119	49
Indo-Gangetic			
Bangladesh	80	103	23
India	75	110	35
Pakistan	75	109	34
Karkheh			
Iran	78	102	24
Limpopo			
Mozambique	92	103	11
Zimbabwe	86	102	16
Mekong			
Cambodia	75	101	26
Lao PDR	72	106	34
Thailand	99	104	5
Vietnam	65	120	55
Nile			
Ethiopia	79	107	28
Kenya	84	106	22
Uganda	86	117	31
Sao Francisco			
Brazil	73	117	44
Volta			
Burkina Faso	76	107	31
Ghana	91	109	18
Yellow River			
China	61	115	54

Source: World Resources Institute, 2005

Fisheries

Over large parts of Africa, Asia, and Latin America, freshwater fisheries provide poor rural families with a high quality food, rich in the protein, minerals, and unsaturated fats needed for the healthy growth of children. Most small fish are eaten whole, thereby contributing significantly to calcium intake.

Global fish production increased from about 20 million tons in 1950 to 125 million tons in 1997. Marine and inland capture fisheries accounted for most of this growth until 1988, when this source of fish peaked at about 88 million tons. Since then, aquaculture has accounted for most of the growth in fish production.

Increasing fish production in irrigation canals and reservoirs

For every 1000 ha of irrigated land, 2.5 km of large canals and 10 km of smaller channels are created. This offers a tremendous potential to foster increased fish production. Success in tapping this potential, however, depends on coordinating water delivery management with the requirements of fish production.

Reservoirs built for river flow regulation, irrigation water storage, and power generation can also be used for fish production. These reservoirs already

play an important role in global fisheries – but there is considerable potential for further expansion. Fish production in reservoirs can result in expanded employment and economic value added.

Increasing fish production in rice fields

Worldwide, there is an estimated 81 million ha of irrigated rice and 11 million ha of flood-prone lands under rice cultivation (Halwart, 1998). It is possible to produce fish in these rice fields, either in capture systems where wild fish enter, reproduce, and are harvested from the flooded fields, or in culture systems where rice fields are stocked with fish, either simultaneously or alternately with the rice crop.

Fish production can significantly increase incomes earned from rice fields. In Cambodia, for example, the value of the fish harvest has been found to be 37-42% of the value of the rice harvest (Guttman, 1999).

A closer look – the Mekong basin

The Mekong River, with more than 1200 species, is a rich source of fish. Most of the estimated 40 million rural people living along the Mekong River, its tributaries and related wetlands, obtain their livelihoods through a combination of rice farming, fishing and foraging from nearby wetlands and forests. Annual per capita fish consumption is 36 kg.

The annual yield of the Mekong's capture fishery is around 1.5 million tons. Total annual freshwater aquaculture production in the lower Mekong basin has risen from 60,000 tons in 1990 to 255,000 tons in 2001. About two million rural households in the lower Mekong basin engage in fish culture.

Cambodia, with an annual catch of close to 400,000 tons, has the fourth largest fishery in the world.

In Thailand more than 6% of the 2.6 million rural households are involved in small-scale aquaculture. In Viet Nam approximately 60-70% of rural households are involved in aquaculture.

A closer look – the Volta basin

In the Volta basin fish production is an important economic activity, particularly in the Oti River in Benin. In Burkina Faso, around 8,000 tons of fish are caught annually, roughly 60-70% of biological potential. In Ghana, the Volta Lake (created by the construction of the Akosombo Dam) produced in 2000 about 87,500 metric tons of fish, accounting for 98% of inland freshwater fish production in Ghana. The recent increases in fish landings from the Volta Lake are the result of deployment of active gear, such as the winch net, with unapproved mesh sizes. This situation endangers a fishery that is already experiencing over-exploitation.

Land Water and Agriculture

Moreover, fish culture in rice fields can actually increase rice yields, especially where soils are infertile and external fertilizer inputs are not used. Recent work by WorldFish Center has shown that rice production costs are reduced by around 10% in flood-prone systems when fish are combined with rice. In addition, the value of harvested fish increased returns per hectare by US\$400 in Bangladesh, US\$340 in the Red River Delta of Vietnam, and US\$220 in the Mekong Delta. These benefits were obtained with no reduction in the wild fish catch.

There are problems, however. Some of the issues confronting fish production in rice fields in the Mekong basin include:

There is a decline in large fish populations. A number of giant fish species are now rare and some are considered endangered within the river.

Golden apple snails (*Pomacea* sp.) from South America were introduced in Cambodia, Thailand, and Vietnam for breeding as a supplementary food source, but escaped captivity and have become a major rice pest.

There are threats to fish biodiversity caused by fragmentation of aquatic habitats, blockages in fish migration routes, changes in water flow patterns, and water levels through dam construction. This has led to water abstraction and water retention, and increased water loss by evaporation.

There has been a decline in fish catches: Some fishers complain that their catches have declined over time. Data from Tonle Sap indicate that fish yield doubled from 1940 to 1995 – but the number of fishers increased many times over, leading to reduced catch per fisher – a classical symptom of a fishery under heavy exploitation.

Summary

There are many options for enhancing food production from fish in managed aquatic systems. The most appropriate technology, however, will vary from place to place, and the conditions under which one technology is preferred over another are still not well defined.

CPWF research approach

Issues, interactions and interventions

Major development issues such as population growth, urbanization, poverty, hunger, food insecurity, and disease have been described. Status and likely trends in land and water resources, and crop, livestock, and fish production have also been discussed. All of these interact. An understanding of these can help identify useful water-related interventions. Some important interactions are illustrated in Figure 1.

Resource availability and quality defines the level of resources available for *allocation and use*. Allocation of resources of a certain quality for a

particular agricultural use, along with the choice of *production system* and related technologies, determine *resource productivity*. The *production system* and its technologies, the level of resources allocated to it, and the level of *resource productivity* achieved, when taken together, determine the composition and level of *agricultural outputs*. Finally, agricultural *production systems*, their technologies, and their corresponding *outputs* influence levels of *income (poverty alleviation)*, and *food, health and environmental securities*. Note that employment generation and equity considerations are implicit in the issues of *resource availability and quality*, *resource allocation*, and the selection of *production systems*.

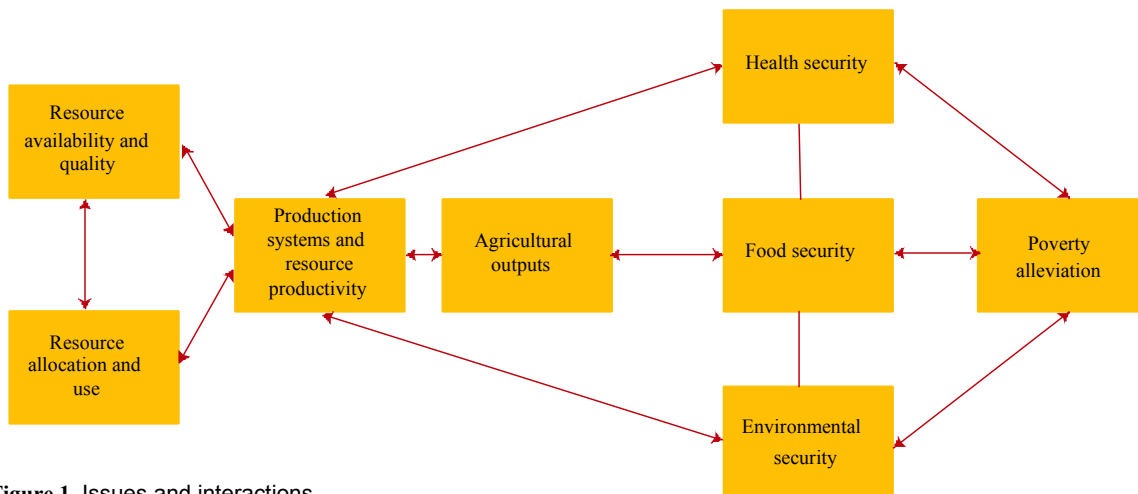


Figure 1. Issues and interactions.

Integrated research on the above set of issues must take account of:

Upstream-downstream interactions: Much past research has focused on improving livelihoods of people managing resources at the farm level. Often, adverse effects on the environment or on people living downstream have been simply ignored. A key challenge lies in understanding the complex tradeoffs between equity, productivity, and efficiency in a given location; the trade-offs between upstream and downstream locations; and integrating this

understanding into a decision-making framework (Molden and de Fraiture, 2004)

Groundwater: In some parts of the world, groundwater use has been a key to improving the livelihoods of the rural poor. There is good potential for further exploitation of groundwater resources. This potential may be constrained, however, by low water quality, unsuitable soil conditions, high costs of groundwater development and pumping, or other factors. Moreover, there already are areas where groundwater is overexploited, where groundwater

resources are being depleted and, as a consequence, where the sustainability of agricultural production systems is threatened (Shah et al, 2000)

The urban-agriculture interface: The swift process of urbanization unfolding in many countries is likely to have many effects on agriculture. These include: increased demand for high-value crops; increased availability of solid waste that might be used to replenish soil fertility – but also increased demand for water for urban use; increased wastewater flow into rivers or groundwater; reduced investment in rural infrastructure (if investment in urban infrastructure takes its place); and slower innovation in agriculture (if skilled entrepreneurs migrate from rural to urban areas). The above factors are likely to have strong health and livelihood repercussions on rural people, but these repercussions are not yet well understood and no clear policies have been developed to mitigate them.

Agriculture-ecosystem interface: In some basins, agricultural area expansion takes the form of encroachment on forest, grasslands and wetlands. Moreover, agricultural intensification often involves use of chemical inputs that inadvertently end up polluting water resources and degrading aquatic ecosystems. Agriculture will have to learn to co-exist with natural ecosystems. Win-win strategies must be sought that will enhance both agricultural production and environmental security.

Examples of interventions

To increase water availability (resource availability and quality)

- Reducing runoff, deep percolation and evaporation loss from crop and grazing land.

- Water storage and conveyance infrastructure and reducing water losses in storage, conveyance, and application.

- Tapping groundwater potential, particularly shallow aquifers and wetland fringes.

- Using marginal quality water - wastewater irrigation.

To foster fair sharing of water resources (resource allocation and use)

- Fair sharing of water resources for the benefit of the poor.

- Sharing benefits, not water, when equal allocations would result in inefficient use.

- Sharing of water conservation and development costs.

To optimize water use benefits (production systems and resource productivity)

- Multiple water use systems such as fish production in rice fields.

- Increasing output per unit of water used by achieving higher water-use efficiency.

- Reallocating water from lower- to higher-value uses.

- Using agricultural byproducts.

To sustain freshwater ecosystems (environmental security)

- Protecting water catchment areas.

- Reducing pollution of water.

- Using aquatic ecosystems sustainably.

- Reducing waterlogging and salinization.

To enhance post-harvesting activity and marketing (agricultural outputs)

- Improving market information.

- Developing post-harvesting technologies that add value and reduce losses.

- Improving transport and communication infrastructure to make it cost-effective to transport produce to distant markets.

Water productivity

In many areas around the world, increases in agricultural production have been exceedingly difficult to achieve, simply because good quality land and water resources are scarce. In such areas, increased production depends entirely on better productivity – more output per unit of input.

Scarcity

The extent of renewable water resources available in a basin depends on recharge, mainly precipitation. However, the availability of soil water, surface water, and groundwater at a given location and time also

depends on how it is managed. When agriculture is the principal user of water in a basin, changes in agricultural practices can have a profound effect on the size, location and quality of water resources.

It is becoming all too common that changes in land management, river flow regulation, water abstraction, and water degradation combine to create situations of severe water scarcity. This is particularly true in areas with limited renewable water resources and rapidly growing water demand. Such areas also become more vulnerable to the effects of drought.

Water scarcity has many undesirable impacts, including:

Environmental impacts: Changes in riparian and aquatic habitats, depletion of fish stocks and species diversity, reduced groundwater recharge and, at times, saltwater intrusion.

Socioeconomic impacts: Financial losses, reduced employment opportunities, and increased incidence of conflict among uses and users.

As resources become scarce, competition among users intensifies, and incentives to use the resource more efficiently begin to emerge. This may prove efficient if strictly enforced.

Productivity

Resource productivity is an output-input relationship. In the context of water use in agriculture, water productivity is defined as agricultural output per unit of water depleted.

Water productivity in agriculture depends on the product being produced, the production system and associated practices, and the biophysical environment.

The process of assessing water productivity

provides insights into trade-offs among alternative water uses. Water productivity assessment is part of a broader water accounting and valuation approach that seeks to provide water users and other key actors with information needed to undertake the interventions needed to achieve water-related societal objectives.

Assessing water productivity

There is, unfortunately, a good deal of ambiguity about how one goes about estimating and quantifying water productivity. Some of this ambiguity has to do with the scale of analysis, what the information will be used for, and which professional disciplines are involved. Most of it, however, has to do with defining the numerator and denominator to be used in the “product/water” output/input ratio.

The *numerator*, agricultural output, can be assessed in physical, nutritional, or monetary terms, within the bounds of the scale and time period considered. Difficulties arise when outputs are difficult to value or when output quantities are expressed in different units. Crop production outputs, for example, may include quantities of grain, fodder for livestock, and organic matter for soil quality improvement.

The numerator for the “product/water” ratio may be expressed in a number of ways:

- Physical measures of total dry vegetative biomass produced.
- Physical measures of the amount of food produced.
- Physical measures of the nutritional content of food produced.
- Economic measures of the value of food produced.

At higher scales of analysis, water productivity estimates may be needed for a group of several crops, for example to compare the water productivity of alternative production systems. The Standardized Gross Value of Production (SGVP) is a good index for this purpose (Molden, 1997), using the formula:

$$SGVP = \sum_{i=1}^N A_i Y_i P_i - P_w$$

Where A_i = the area cropped with crop i , Y_i = yield of crop i , P_i = local price of crop i , P_w is the local price of base crop (the main locally-grown, internationally-traded crop) and P_w is the value of the base crop traded at world prices and N = number of crops grown.

Defining the numerator of the “product/water” ratio may be complicated by many factors:

- Non-grain benefits of water use in crop production.
- Benefits from by-products in agricultural, livestock, or fisheries production.
- Derivative outputs.
- Valuing the benefits from environmental uses of water

The *denominator* of the “product/water” ratio can be expressed as total seasonal rainfall, irrigation water diverted or water depleted through evapotranspiration – whichever is most appropriate for the production system in question. Estimates of the denominator typically require a water accounting system to keep track of inflows, flow paths, processes, and outflows of water.

Water depletion is estimated in similar ways regardless of whether the water is used in crop production, livestock or fisheries production, urban and industrial use, or for environmental services. In all cases, the amount of water depleted is that made unavailable for reuse (through evaporation, contamination or flow to a saline sink).

Scale of analysis

Water productivity can be assessed at many different scales, for example:

- Individual producers (plant, field and farm).
- Interrelated individual producers (community, irrigation unit, entire irrigation project).
- Hydrologic unit (catchment, sub-basin, basin).
- Administrative unit (locations, divisions, districts, provinces, countries).
- Agroecological zones.

Different combinations can be used to produce a nested scale of analysis such as: plant, field, farm, catchment, sub-basin and basin, or, alternatively, plant, field, farm, district, province and country.

The basic research process

The basic research approach of the CPWF (Figure 2) is one of problem-solving. Program partners conduct research to develop water-related interventions – especially those linked to water productivity – that can assist in solving important problems of poverty, food security, health, and the environment. At the heart of the CPWF’s approach, then, lies the issue of water and land productivity.

Some research activities (*scoping*) aim to identify and better understand problems. Other activities (*innovation*) seek to develop or identify alternative solutions. And others (*outreach*) aim to transform research results into viable strategies for local adoption, while encouraging feedback and assessment.

Scoping has been used at many levels. At the global level, it led to the selection of the five themes around which all other Program activities are organized. Scoping at the basin level featured extensive consultation and resulted in the selection of basin priorities.

Most CPWF resources, however, are devoted to “innovation,” the search for solutions in the form of technologies, institutional arrangements, or policies. Major investments in outreach have not yet been made.

Themes

Within this problem-solving process, the CPWF performs research at geographic (i.e., benchmark basins) and thematic levels. CPWF’s *themes* focus on those disciplinary areas where greatest water productivity impact is likely to be achieved. They are a means for addressing issues and packaging information at different scales and with slightly different perspectives on issues related to water productivity. The five themes are “crop water productivity improvement”, “water and people in

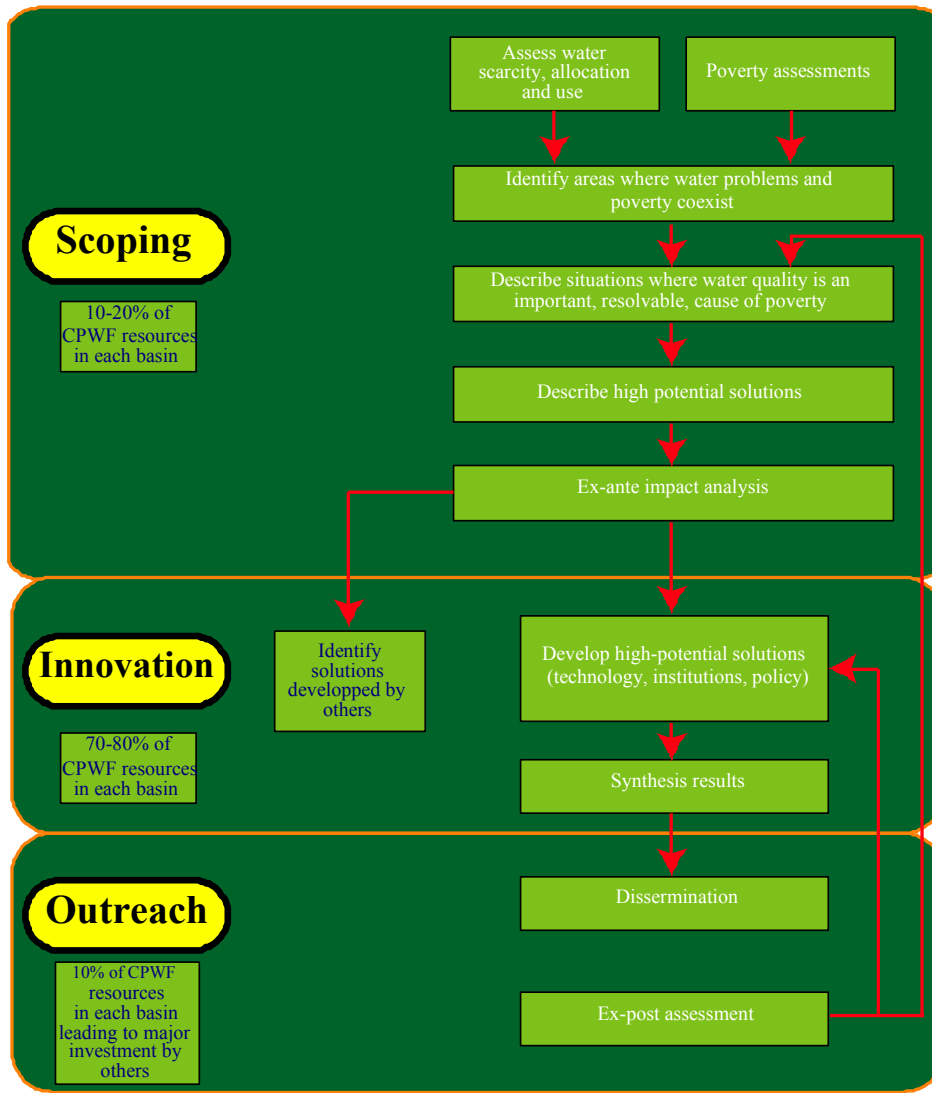


Figure 2. Basic research process of the CPWF

catchments,” “aquatic ecosystems and fisheries”, “integrated basin water management systems”, and “global and national water and food systems.” The theme hierarchy is illustrated in Figure 3.

CPWF’s benchmark *basins*, in turn, serve as “real-life” laboratories within which research is conducted and where outputs will be applied and achieve impact. The selected basins are described earlier. *Priorities* for research within a basin are

chosen by partners as they reflect on developmental and water productivity problems characteristic of the basin, how these problems might be solved, and how they unfold with respect to CPWF themes. Finally, specific *projects* are chosen that address the top priorities within (or, occasionally, across) basins. A major challenge for CPWF management is to ensure that the set of projects selected for a basin, when taken together, add up to a coherent whole.

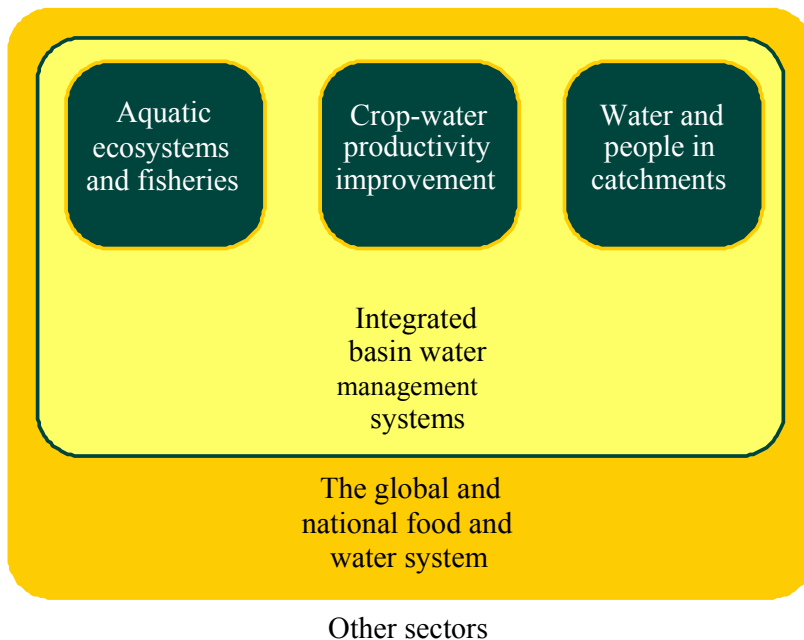


Figure 3. System hierarchy among the CPWF themes. Note that there are significant interactions among all the sub-systems.

Crop water productivity improvement

This theme brings the scale of analysis down to the plot, the farm, and the agroecosystem, with a strong emphasis on improving agricultural water productivity despite drought, floods, salinity, and other abiotic stresses. Ways to achieve this include crop improvement for abiotic stress tolerance, and conservation agriculture practices (for example, zero and reduced tillage, permanent bed systems, laser leveling, water harvesting, crop residue management) to enhance crop and livestock yields while conserving soil and water resources.

Policies and institutions that influence adoption of suitable farm-level technologies are also examined, and how these policies and institutions might be modified to accelerate adoption.

Ultimately, work associated with this theme aims to enable poor people to benefit from improved water productivity through higher levels of production, increased opportunities for employment, growth in the local non-farm economy, and lower food prices.

Thematic priorities:

- Plant level perspective: impact and future directions of plant breeding.
- Crop and field perspective: New opportunities for integrated natural resource management.
- Agro-ecological System level: land and water management.
- Policies and Institutions facilitating adoption of improvements.

Expected outputs:

- Varieties tolerant to drought, salinity, and other stresses.
- Innovative soil, crop and water management technologies and practices for increasing crop water productivity.
- Targeting of new varieties and management practices to those areas within a basin where they are most likely to be attractive to farmers.
- Suggested policies and institutional arrangements to accelerate adoption of suitable practices.
- Information on the basin-level consequences of plot- or farm-level interventions.

Water and people in catchments

This theme has a direct focus on externalities and equity. How water is used in upper catchments influences the livelihoods of people living there – and also the livelihoods of those living downstream. The goal is to improve upstream water productivity in irrigation systems or rainfed crop/ livestock systems, in ways that also improve water availability and quality for downstream uses. There is a heavy emphasis on creating incentives for improved upstream water management. Possible mechanisms include payments for environmental services, and building social assets to enhance social adaptive capacity for addressing water scarcity problems.

Thematic priorities:

- Water, poverty and risk in catchments
- Identifying the potential for improving land and water management
- Enabling people to benefit from improved management of land and water resources

Expected outputs:

- A better understanding of the relationship between water and poverty.
- Decision support information on policies and management practices for effective water management for poverty alleviation.
- Institutional innovations to enhance equitable water management at the catchment level.

Aquatic ecosystems and fisheries

This theme focuses on water productivity in aquatic ecosystems and fisheries. It embraces livelihood issues (animal grazing on river floodplains, fish culture) as well as environmental dimensions (biodiversity in aquatic systems, environmental services provided by aquatic systems) and explores how both might be enhanced.

Thematic priorities:

- Policy, institutions and governance.

- Valuation of ecosystem goods and services, and the cost of degradation.
- Environmental water requirements.
- Improving water productivity.

Expected outputs:

- Policies and institutional arrangements for better management of aquatic ecosystems and fisheries.
- Information (and methods) for assessing the value of ecosystem goods and services.
- Mechanisms for allocating water for ecosystems and environmental services.
- Improved fisheries management practices for sustainable improvement in fish yields.

Integrated basin water management systems

This theme seeks ways to improve basin-level agricultural water productivity; to explore the effectiveness in different parts of the basin of resource-conserving and yield-enhancing technologies; to assess basin-level interventions for water infrastructure (storage, conveyance) and management (land use planning, water allocation among users); and to explore basin-level institutional arrangements for water governance, and for fair sharing in the costs and benefits of water resource development and use.

Thematic priorities:

- Integrated decision support tools and information.
- Innovative technologies and management strategies.
- Effective policies and institutional mechanisms.

Expected outputs:

- Basin-level technologies and management strategies that help poor farmers enhance water productivity, agricultural output, and food security.
- Basin-level policies and institutions for enhancing water productivity in ways that benefit the poor as well as the environment.
- Decision-support and information systems to inform basin stakeholder decision-making.

Global and national water and food systems

This theme examines the effects of global and national issues on agriculture, water management, food security and poverty. Issues include global change (climate, trade); global conventions (biodiversity, desertification); national macroeconomic and sectoral policies (trade, public finance, environment, investments in water resource development); and transboundary water policies within a basin.

Thematic priorities:

- Globalization, trade macroeconomic and sectoral policies.
- Incentives, investment and financing of agricultural water development and water supply.
- Transboundary water policy and institutions.
- Adapting to changes in the global water cycle.

Expected outputs:

- Policies and institutional mechanisms for mitigating negative impacts of globalization, trade, macroeconomic and sectoral policies on water and food security.
- Strategies for providing incentives and directing investments and financing for water in agriculture.
- Mechanisms (institutions, allocation mechanisms, conflict prevention and resolution) for sharing transboundary waters.

Themes as spotlights

The five themes may be seen as spotlights that serve to illuminate important developmental and water-related issues associated with any particular basin, with one or two of them particularly “well-placed” to inform decision-making regarding basin-level priorities and identifying effective interventions.

Taken together, research priorities for a particular basin must be coherent. They must feature an internal logic that makes sense, regardless of links to other CPWF activities. They must show a credible process whereby important problems are identified, defined, and solved in ways that meet

developmental objectives. A major role of thematic research is to ensure that basin-level research achieves coherence, that all important issues are considered, and that none remain in the dark.

In the 2005 CPWF Medium Term Plan, basin research is said to aim for productive impacts through the uptake and application of research results, whereas thematic research is said to aim for scientific outcomes through the production of scientific research information.

Crossing thematic boundaries

Often, the five themes complement each other, with some research projects simultaneously touching on several themes. The following are examples of research questions that cross thematic boundaries.

“Integrated basin water management” and “Crop water productivity”

Where is the potential greatest within the basin for expanding cropped area, or for diversifying cropping systems?

Which land or water management technologies have the greatest promise for improving crop level water productivity? For which parts of the basin?

What will be the impacts at the basin level of practices that improve farm-level water productivity? Who will benefit? Will some basin inhabitants be harmed?

“Integrated basin water management” and “Water and people in catchments”

How do land and water users in upper and lower parts of the watershed impact each other in terms of resource flows (water, sediment, pollutants, food, human migration and capital transfers)?

What mechanisms may be used to help facilitate effective and acceptable sharing of costs and benefits of measures that aim to reduce the downstream impacts of upstream water use?

“Integrated basin water management systems” and “Aquatic ecosystems and fisheries”

What water quality and quantity targets are needed to safeguard the ecological integrity and productivity of aquatic ecosystems?

What land/water management strategies can help attain these targets? Who will be harmed in the event these strategies are implemented?

“Integrated basin water management systems” and “Global and national water and food systems”

What are the institutional requirements (policy, legal, and institutional framework) for increasing water productivity and for increasing investments in water resource development?

How should transboundary water resources be governed?

Applying the research approach

Basins and sub-basins

As priorities are set and research commences, different kinds of sub-basins, each with a different package of challenges, may become items of interest. Some of these are:

Sub-basins where current levels of water withdrawals are low, but where pressure is increasing to extract more water. Here, the challenge is to develop water resources in ways that avoid pitfalls experienced in other basins.

Sub-basins where water resources have already been intensively developed but current levels of water withdrawals for agriculture are not sustainable. Here, the challenge is to restore the system to sustainable limits, perhaps through water demand management and reallocation strategies.

Sub-basins where groundwater resources are managed in ways that permit groundwater mining, waterlogging, and salinity, or groundwater pollution from agricultural, industrial and other activity.

Sub-basins where marginal water and land resources are used for agricultural production, for example, irrigation with wastewater or saline water, or cultivating highly degraded or erodible lands.

Complementarities and trade-offs

Achieving food security and environmental security are equally important. But is it possible to achieve both? If food and environmental security can both

be increased at the same time, then the two are complementary. However, if an increase in one implies a decrease in the other, then there are trade-offs. If policy makers, planners, and resource users are to take sensible decisions, it is important they understand the complementarities and trade-offs involved.

Complementarities between food and environmental security are often hard to discern, because of a spatial disconnect (the distance between upstream areas where water is saved and downstream aquatic environments that benefit from upstream water savings) and a temporal disconnect (the time delay between implementing an intervention and its impact on the downstream environment).

An example of complementarity: Upstream land/water users invest in technologies that enhance the environmental security of a downstream aquatic ecosystem. They do so by adopting conservation agriculture measures that improve their crop yields and reduce their production costs. They see the improvement in downstream water flow as purely incidental. However, reduced environmental degradation of the downstream aquatic ecosystem leads to increased fish production, reducing the price of fish for both upstream and downstream consumers. And wealthier downstream communities increase their demand for high value commodities only produced upstream. Everyone wins.

Examples of trade-offs: Wetland fringes are used for agriculture *instead of* for the provision of environmental goods and services, or upstream water resources are depleted during irrigation for agricultural production *instead of* allowing them to revitalize a downstream aquatic ecosystem. If someone wins, someone else loses.

As a rule, complementarity should be sought and trade-offs minimized. Research helps identify and explore complementarities and trade-offs – through valuation of resources, through ex-ante analysis of interventions, and through the design of institutional mechanisms that allow complementarity to unfold.

Building communities of practice

The basic CPWF approach aims to foster knowledge sharing among partners. One way to achieve this is by building communities of practice. A community of practice can bring together like-minded professionals with shared interests (though possibly from different disciplines) to facilitate a high level of professional interaction and cross-fertilization

of ideas; to provide technical backstopping and advice to other projects (possibly even in other basins); to develop a framework for integrating research findings from different studies; and to synthesize study findings and provide guidelines on how study findings can be disseminated to achieve a higher impact within and beyond the CPWF benchmark basins.

Basins, priorities and projects

Research priorities indicate the relative urgency for conducting particular kinds of research on different problems. Typically, the selection of priorities is influenced by the importance and incidence of the problem, the likelihood of solving it, the level of investment required, the time period over which adoption of a problem-solving intervention is expected to unfold, and the discount rate used to convert future costs and benefits into present values.

Interestingly, all of these can change over time. Improved understanding of a problem may show it to be more important than had been previously thought. The discovery of an innovative new technology may improve the likelihood of solving the problem. Or, the research investment may prove to be smaller than had been anticipated. Consequently, research priorities are likely to evolve.

Such has been the case with priorities for CPWF research. Thematic priorities (discussed above) were developed by Thematic Advisory Groups in 2002. Benchmark basin priorities first were developed in basin “kick-off” workshops, held during 2002-03. Some basins listed as few as six priorities; others listed as many as fourteen. Priorities as developed by the kick-off workshops were summarized in a 2003 series of reports released by the CPWF.

Theme and basin priorities were then organized and synthesized within the context of a single matrix (the “concordance”). As discussions continued, a list emerged of the top priorities for each basin. Finally, all of the above material was integrated and

a set of priorities was proposed that aimed to cover all themes and all basins. The priorities described below are those contained in the 2005 CPWF Medium Term Plan.

The priorities and projects for each basin are presented in the following set of boxes. The 50 projects approved as part of the first call by the CPWF for competitive grant proposals are – with a few exceptions – reasonably well distributed across basins and themes. The projects are listed in abbreviated form in Table 4, with each one identified with respect to basin and theme.

Among basins, it appears that the Yellow River is under-represented. Among themes, Theme 5 is under-represented, having only seven projects (compared to 49 projects for crop water productivity). Moreover, projects for Theme 5 tend to focus on only one sub-theme: transboundary water allocation.

It should be noted that assessing project distribution across themes and basins is complicated by projects that cross themes, or that specifically seek to make cross-basin comparisons. Cross-theme projects are desirable as they facilitate a more holistic approach to the issues. Considering the importance of improving crop water productivity while assessing downstream consequences, it might have been better if more cross-thematic projects included Theme 1. A similar argument can be made with respect to Theme 3. Cross basin projects were intended to facilitate comparison and transfer of experiences from different basins. The level of true cross-basin activity is quite low, however.

Table 4. CPWF projects

Priority Area code	Output	Andes Basin	Indo-Gangetic Basin	Karkheh Basin	Limpopo Basin	Mekong Basin	Nile Basin	Sao Francisco Basin	Volta Basin	Yellow Basin	Other Basin
1.1	First generation and prototype aerobic rice germplasm (16)		x			x				x	x
1.1	Improved drought tolerant sorghum, cowpea and cassava varieties (6)								x		
1.1	Improved drought tolerant varieties of barley, wheat, chickpea, lentil, faba bean, cowpea (2)						x				
1.1	New generation of salt-tolerant breeding lines and varieties (7)		x			x	x				
1.2	Crop production in wetlands (30)										
1.2	Developments of alternative seed delivery mechanisms (2)						x				
1.2	Improved rice based cropping systems (11)					x					
1.2	Options for rainwater harvesting (6)								x		
1.2	Strategies for efficient cropping systems (7)		x			x	x				
1.2	Technologies for improving crop water productivity (8)			x							
1.2	Technologies for improving water and nutrient use efficiency and crop productivity (5)								x		
1.2	Tools for evaluating water, nutrient and crop management technologies (5)								x		
1.2	Vegetable production using waste water (38)								x		
1.3	Crop production risk management strategies (17)				x						
1.3	Decision support tools for integrating multiple uses of water (10)		x			x					
1.3	Drought detection and mitigation strategies (6)								x		
1.3	Ecologically friendly rice-aquaculture production systems (10)		x			x					
1.3	Enhanced adoption of drought-tolerant crops (1)				x						
1.3	Options for regulating soil water cycle and carbon storage (15)				x		x		x		
1.3	Spatial and temporal variability of water and impact on crop yield (10)		x			x					
1.3	Strategies for validation and diffusion of technologies (7) + (11)		x			x	x				
1.3	Tools and methods for quantifying water quality (15)				x		x		x		
1.3	Trade-off between water use and yield of aerobic rice (16)		x			x			x	x	
1.4	Impact of regional and farm level resources on livelihood at farm level (10)		x			x					
1.4	Institutional and policy options for improved crop water productivity (8)			x							
1.4	Institutional arrangements for enhancing livelihood resilience in arid lands (24)			x							
1.4	Institutional framework for rice-aquaculture systems (10)		x			x					
1.4	Market institutional innovations (5) + (1)				x				x		

2.1 Impacts of payment of environmental services on poverty (22)	x							
2.1 Methods of assessing diversity and dynamics of livelihoods (24)			x					
2.1 Options for enhancing forest and water based livelihoods (23)		x						
2.2 Guidelines for allocation wetland resources (3)			x					
2.2 Guidelines for catchment management (17)			x					
2.2 Guidelines on scaling up integrated forest and water management (23)		x						
2.2 Options for managing watersheds in arid lands (24)			x					
2.2 Participatory planning of land and water management for conflict resolution (11)					x			x
2.3 Guidelines for multiple use water supply systems (28)	x	x	x	x	x			
2.3 Impact of QSMAS on farmer's income (15)			x		x		x	
2.3 Options for payments for environmental services (22)								
2.3 Water sharing mechanisms (25)				x				
3.1 Institutional mechanisms for integrating fish and crop production (35)		x		x				x
3.2 Ecological goods and services of wetlands (30)			x					
3.4 Co-management strategies for reservoir fisheries (34)		x				x	x	
3.4 Methodologies for assessing water productivity in fisheries (35)		x		x				x
3.4 Methodologies for integrating fish and crop production (35)		x		x				x
4.1 Basin/Watershed water assessment tools (46)	x		x			x		
4.1 Economic-Hydrologic models (40)	x						x	
4.1 Hydrologic and agronomic models (25)				x				
4.1 Livestock and environmental DSS (37)					x			
4.1 Water allocation/management negotiation tools (50)				x				
4.1 Reservoir planning and management tools (46)	x		x			x		
4.1 Stakeholder communications tools and models (40)	x						x	
4.1 Tools for land use decision making (22)	x							
4.1 Tools for reservoir management for fisheries (34)		x				x	x	
4.1 Trade-off analysis tools (30)			x					
4.2 Health risk reduction strategies (38)							x	
4.2 Impacts of intensification and diversification on water quantity and quality (15)			x		x		x	
4.2 Livestock production hotspots and solutions options (37)					x			
4.2 Options for waste water utilization (38)							x	
4.2 Wetland management strategies (30)			x					
4.3 Institutional arrangements for water and forest management (23)		x						
4.3 Institutional innovations (47)			x				x	
4.3 Institutional models for water governance (17)			x					
4.3 Livestock management policies (37)					x			
4.3 Options for enhancing water governance (40)	x						x	
5.3 Options for enhancing transboundary water governance (17) + (23) + (37) + (40) + (47)	x	x	x		x		x	

Table 5. Distribution of projects across themes and basins.

Priority areas	Number of outputs by Basin										
	Andes Basin	Indo-Gangetic Basin	Karkheh Basin	Limpopo Basin	Mekong Basin	Nile Basin	Sao Francisco Basin	Volta Basin	Yellow Basin	Other basin	Total
1. Crop Water Productivity Improvement	0	10	3	6	9	8	0	9	2	2	49
1.1. level perspective: Impact and future directions of plant breeding		2			2	2		1	1	1	9
1.2. Crop and field perspective: New opportunities for integrated natural resource management		1	1		2	3		4			11
1.3. Agro-ecological System level: land and water management		5		4	5	3		3	1	1	22
1.4. Policies and Institutions facilitating adoption of improvements		2	2	2				1			7
2. Water and People in Catchments	2	3	2	4	2	2	0	1	0	1	17
2.1. Water, poverty and risk in catchments	1	1	1								3
2.2. Identifying the potential for improving land and water management		1	1	2	1					1	6
2.3. Enabling people to benefit from improved management of land and water resources	1	1		2	1	2		1			8
3. Aquatic Ecosystems and Fisheries	0	4		1	3	0	0	1	1	1	11
3.1. Policy, institutions and governance		1			1					1	3
3.2. Valuation of ecosystem goods and services, and the cost of degradation				1							1
3.3. Environmental water requirements											0
3.4. Improving water productivity		3			2			1	1		7
4. Integrated Basin Water Management Systems	6	2	0	7	2	4	3	8	0	0	32
4.1. Integrated decision support tools and information	5	1		3	2	1	3	3			18
4.2. Innovative technologies and management strategies				2		2		3			7
4.3. Effective policies and institutional mechanisms	1	1		2		1		2			7
5. The Global and National Food and Water System	1	1	0	2	0	1	0	2	0	0	7
5.1. Globalization, trade macroeconomic and sectoral policies											0
5.2. Incentives, investment and financing of agricultural water development and water supply											0
5.3. Transboundary water policy and institutions	1	1		2		1		2			7
5.4. Adapting to changes in the global water cycle											0
Total by Basins	9	20	5	20	16	15	3	21	3	4	116

Andes

Here are the research priorities and research agenda for the Andes basin.

Basin priorities focus on upstream – downstream conflicts, governance systems, and water management institutions. There is much less of a focus on crop-water productivity or aquatic ecosystems. This is reflected in the set of approved projects for the Andes, which are largely devoted to Theme 2 (Water and people in catchments) and, to a lesser extent, Themes 4 and 5.

Priorities

Upstream-downstream conflicts: trade-offs and environmental externalities of catchment management (Theme 2).

Developing governance systems that foster equitable and sustainable management of aquatic resource systems (Themes 3 and 5).

Institutional mechanisms for improved water management including market-oriented approaches in transboundary water sharing, water pricing, and user rights (Theme 5).

Projects	Theme 1- Crop water productivity improvement	Theme 2- Water and people in catchments	Theme 3- Aquatic ecosystems and fisheries	Theme 4- Integrated basin water management systems	Theme 5- Global and national water and food systems
Sustaining inclusive collective action that links across economic and ecological scales in upper watersheds (SCALES) (20).		50%		25%	25%
Payment for environmental services as a mechanism for promoting rural development in the upper watersheds of the tropics (22).	5 %	60%		18%	17%
Models for implementing multiple-use water supply systems for enhanced land and water productivity, rural livelihoods and gender equity (28).	20%	50%	10%	10%	10%
Scaling water use, quality and equitable water distribution issues in the Andes and Himalayas (29).		100%			
Integrating knowledge from computational modeling with multi-stakeholder governance: towards more secure livelihoods through improved tools for integrated river basin management (40).		40%		50%	10%

Indus-Ganges

Here are the research priorities and research agenda for the Indus-Ganges basin.

Basin priorities focus on groundwater management, aquatic resources, water access, and the downstream consequences of catchment management. There is less of an emphasis on crop water productivity. In the project portfolio, however, crop water productivity is well represented. Access to water resources by the poor is not the main focus of any project, but is an important component of several of them. The project portfolio is not as strong in the area of catchment management as would be suggested by the priorities.

Priorities

Policies and management strategies for sustainable groundwater irrigation (Themes 4 and 5 – but presumably Theme 1 touches on this as well).

Upstream-downstream conflicts: trade-offs and environmental externalities of catchment management (Theme 2).

Developing tools for measuring water productivity that include fisheries and aquaculture (Theme 3).

Developing governance systems that foster equitable and sustainable management of aquatic resource systems (Themes 3 and 5).

Rights and access to water by the poor, women and socially excluded groups in the process of global change (Theme 5).

Projects	Theme 1- Crop water productivity improvement	Theme 2- Water and people in catchments	Theme 3- Aquatic ecosystems and fisheries	Theme 4- Integrated basin water management systems	Theme 5- Global and national water and food systems
Development of technologies to harness the productivity potential of salt-affected areas of the Indo-Gangetic, Mekong, and Nile River Basins (7).	100%				
Managing water and land resources for sustainable livelihoods at the interface between fresh and saline water environments in Vietnam and Bangladesh (10).	50%		50%		
Developing a system of temperate and tropical aerobic rice (STAR) in Asia (16).	100%				
Linking community-based water and forest management for sustainable livelihoods of the poor in fragile upper catchments of the Indo-Gangetic Basin (23).	20%	50%		20%	10%
Improved fisheries productivity and management in tropical reservoirs (34).	5 %	10%	70%	10%	5 %
Community-based fish culture in irrigation systems and seasonal floodplains (35).	10%		60%	20%	10%
Energy supply, pricing and power infrastructure management: indirect tools for groundwater management in the Indo-Gangetic Basin (41).				75%	25%
Groundwater governance in Asia: capacity building through action research in Indo-Gangetic and Yellow River Basins (42).	10%	5 %		50%	35%
Strategic analysis of India's National River-Linking Project (48).	5 %	10%	15%	20%	50%
Revisiting the impacts of irrigation: Implications for poverty reduction, environment, financing, and water management at irrigation system level (49)	20%	10%	10%	30%	30%

Karkheh

Here are the research priorities and research agenda for the Karkheh basin.

Basin priorities focus on the management of rainwater and irrigation water, including floods and droughts, groundwater governance and aquatic system management. Given the small number of projects approved for the Karkheh, the heavy emphasis in the project portfolio on rainwater and irrigation water management is understandable.

Priorities

Improvement of management and use of water in irrigation areas with water shortage and/or salinity problems (Theme 1)

Development of sustainable production systems to improve livelihoods in areas with low and erratic rainfall (Theme 4)

Management of flood and drought risks (Themes 2 and 4)

Development of governance systems that foster equitable and sustainable management of aquatic resource systems (Themes 3 and 5)

Policies and management strategies for sustainable groundwater irrigation (Themes 4 and 5)

Projects	Theme 1- Crop water productivity improvement	Theme2- Water and people in catchments	Theme 3- Aquatic ecosystems and fisheries	Theme 4- Integrated basin water management systems	Theme 5- Global and national water and food systems
Improving on-farm agricultural water productivity in the Karkheh River Basin (8).	60%	20%		10%	10%
Improving the productivity, sustainability and water use efficiency of rainfed cereal-based systems in the River basin through conservation agriculture (9).	50%	35%		10%	5%
Strengthening livelihood resilience in upper catchments of dry areas by integrated natural resources management (24).	20%	65%		5%	10%

Limpopo

Here are the basin priorities and research agenda for the Limpopo.

Priorities in this nearly “closed” basin focus on management of agroecosystems in rainfed, drought-prone areas, governance systems for water allocation (especially in the relatively scarce “wetlands”), and investment priority-setting. Approved projects for the basin actually go beyond these priorities, embracing such topics as adapting to global change and transboundary river basin governance. Only two of eight approved projects focus specifically on livelihoods improvement in rainfed, drought-prone areas.

Priorities

Development of production systems to improve livelihoods in areas with low and erratic rainfall (Themes 1 and 4)

Management of flood and drought risks (Themes 2 and 4)

Development of governance systems that foster equitable and sustainable management of aquatic resource systems (Themes 3 and 5)

Role of public and private sector investments to optimize allocation within the agricultural sector and optimal investments in water use sectors vs. other kinds of investments in poverty alleviation (Theme 5)

Projects	Theme 1- Crop water productivity improvement	Theme 2- Water and people in catchments	Theme 3- Aquatic ecosystems and fisheries	Theme 4- Integrated basin water management systems	Theme 5- Global and national water and food systems
PN 1* Increased food security and income in the Limpopo basin through integrated crop, water and soil fertility options and public private partnerships	70%	20%		10%	
PN 17* The challenge of integrated water-resources management for improved rural livelihoods: Managing risk, mitigating drought and improving water productivity in the water-scarce Limpopo basin	33%	35%		32%	
PN 28* Models for implementing multiple-use water supply systems for enhanced land and water productivity, rural livelihoods and gender equity	20%	50%	10%	10%	10%
PN 29 Scaling water use, quality and equitable water distribution issues in the Andes and Himalayas		100%			
PN 30* Wetlands-based livelihoods in the Limpopo basin: Balancing social welfare and environmental security	10%	30%	30%	30%	
PN 46* Planning and evaluating ensembles of small, multipurpose reservoirs for the improvement of smallholder livelihoods and food security: Tools and procedures		25%	15%	50%	10%
PN 47* Transboundary water governance for agricultural and economic growth and improved livelihoods in the Limpopo and Volta basins: Towards African indigenous models of governance	10%	10%	5%	40%	40%
PN 53* Food and water security under global change: developing adaptive capacity with a focus on rural Africa					100%

Research Agenda

Priorities

Development of production systems to improve livelihoods in areas with low and erratic rainfall (Theme 4).

Management of flood and drought risks (Themes 2 and 4).

Development of governance systems that foster equitable and sustainable management of aquatic resource systems (Themes 3 and 5).

Role of public and private sector investments to optimize allocation within the agricultural sector and optimal investments in water use sectors vs. other kinds of investments in poverty alleviation (Theme 5).

Projects

Increased food security and income in the Limpopo basin through integrated crop, water and soil fertility options and public-private partnerships (1).

The challenge of integrated water resources management for improved rural livelihoods: Managing risk, mitigating drought and improving water productivity in the water-scarce Limpopo basin (17).

Models for implementing multiple-use water supply systems for enhanced land and water productivity, rural livelihoods, and gender equity (28).

Wetlands-based livelihoods in the Limpopo basin: balancing social welfare and environmental security (30).

Improved planning of large dam operations: Using decision support systems to optimize livelihood benefits, safeguard health and protect the environment (36).

Planning and evaluating ensembles of small, multipurpose reservoirs for the improvement of smallholder livelihoods and food security: tools and procedures (46).

Transboundary water governance for agricultural and economic growth and improved livelihoods in the Limpopo and Volta basins: towards African indigenous models of governance (47)

Food and water security under global change: developing adaptive capacity with a focus on rural Africa (53)

Mekong

Here are the basin priorities and research agenda for the Mekong.

Some basin priorities pertain to upper catchments, some to coastal areas, and some to the entire basin. In general, there is a heavy emphasis on governance systems, externalities and trade-offs, e.g., upstream-downstream conflicts, pollution, governance for aquatic systems, and transboundary water sharing. Although basin priorities do not emphasize crop water productivity as such, some projects focus on this. Regarding governance issues, projects feature model development and use in decision-support. Issues relating to flooding – but not drought – are covered by the projects.

Basin Priorities

Upstream-downstream conflicts: trade-offs and environmental externalities of catchment management (Theme 2)

Management of flood and drought risks (Themes 2 and 4)

Social and economic costs of degradation of aquatic ecosystems (Theme 3)

Development of governance systems that foster equitable and sustainable management of aquatic resource systems (Themes 3 and 5)

Policies and management strategies for sustainable groundwater irrigation (Themes 4 and 5)

Institutional mechanisms for improved water management including market-oriented approaches in transboundary water sharing, water pricing, and user rights (Theme 5)

Projects	Theme 1- Crop water productivity improvement	Theme 2- Water and people in catchments	Theme 3- Aquatic ecosystems and fisheries	Theme 4- Integrated basin water management systems	Theme 5- Global and national water and food systems
PN 10* Managing water and land resources for sustainable livelihoods at the interface between fresh and saline water environments in Vietnam and Bangladesh	50%		50%		
PN 11* Rice landscape management for raising water productivity, conserving resources and improving livelihoods in upper catchments of the Mekong and Red river basins	60%	40%			
PN 16* Developing a System of Temperate and Tropical Aerobic Rice (STAR) in Asia	100%				
PN 25* Companion modeling for resilient water management: Stakeholder's perceptions of water dynamics and collective learning at the catchment scale		80%		20%	
PN 27 Forests, water and land-use mosaics: catalyzing change in upper catchments		60%		20%	20%
PN 33 Effects of water-control schemes on water productivity and multi-scale impacts: Tools for assessment and management	10%	10%	35%	35%	10%
PN 35* Community-based fish culture in irrigation systems and seasonal floodplains	10%		60%	20%	10%
PN 50* Multi-scale Mekong water governance: Interdisciplinary research to enhance participatory water governance from local watersheds to regional scales	5 %	10%	5 %	40%	40%
PN 52* Strengthening Fisheries Management Institutions in the Lower Mekong River Basin through Collaborative Research and Data Synthesis across Multiple Scales			100%		

Research agenda

Priorities

Development of production systems to improve livelihoods in areas with low and erratic rainfall (Theme 4).

Management of flood and drought risks (Themes 2 and 4).

Development of governance systems that foster equitable and sustainable management of aquatic resource systems (Themes 3 and 5).

Role of public and private sector investments to optimize allocation within the agricultural sector and optimal investments in water use sectors vs. other kinds of investments in poverty alleviation (Theme 5).

Projects

Increased food security and income in the Limpopo basin through integrated crop, water and soil fertility options and public-private partnerships (1).

The challenge of integrated water resources management for improved rural livelihoods: Managing risk, mitigating drought and improving water productivity in the water-scarce Limpopo basin (17).

Models for implementing multiple-use water supply systems for enhanced land and water productivity, rural livelihoods, and gender equity (28).

Wetlands-based livelihoods in the Limpopo basin: balancing social welfare and environmental security (30).

Improved planning of large dam operations: Using decision support systems to optimize livelihood benefits, safeguard health and protect the environment (36).

Planning and evaluating ensembles of small, multipurpose reservoirs for the improvement of smallholder livelihoods and food security: tools and procedures (46).

Transboundary water governance for agricultural and economic growth and improved livelihoods in the Limpopo and Volta basins: towards African indigenous models of governance (47)

Food and water security under global change: developing adaptive capacity with a focus on rural Africa (53)

Nile

Here are the basin priorities and research agenda for the Nile.

The list of basin priorities is relatively long. This is matched by the large number of projects approved for this basin. Priorities emphasize groundwater management, water productivity improvement for irrigated crops, improvement of fisheries, and the development of governance systems. There is less of an emphasis on catchment management or on livelihoods improvement in rainfed, drought-prone areas.

Curiously, approved projects for the basin do in fact provide good coverage for water productivity improvement for crops and livestock in dryland areas. Several projects also focus on catchment management, more than the priorities might have suggested. In contrast, there is little project activity on groundwater management or crop water productivity in irrigated agriculture.

Basin Priorities

Improvement of management and use of water in irrigation areas with water shortage and/ or salinity problems (Theme 1)

Upstream-downstream conflicts: trade-offs and environmental externalities of catchment management (Theme 2)

Management of flood and drought risks (Themes 2 and 4)

Decision support tools for holistic management of aquatic resources at basin scale (Theme 2)

Developing tools for measuring water productivity that include fisheries and aquaculture (Theme 3)

Development of governance systems that foster equitable and sustainable management of aquatic resource systems (Themes 3 and 5)

Policies and management strategies for sustainable groundwater irrigation (Themes 4 and 5)

Tools for assessing trade-offs in groundwater utilization (Themes 4 and 5)

Role of public and private sector investments to optimize allocation within the agricultural sector and optimal investments in water use sectors vs. other kinds of investments in poverty alleviation (Theme 5)

Research agenda

Projects	Theme 1- Crop water productivity improvement	Theme2- Water and people in catchments	Theme 3- Aquatic ecosystems and fisheries	Theme 4- Integrated basin water management systems	Theme 5- Global and national water and food systems
PN 2* Improving water productivity of cereals and food legumes in the Atbara river basin of Eritrea	85%	5 %		5 %	5 %
PN 3 Barley improvement in the Upper Blue Nile river basin and the Atbara river basin in Ethiopia	85%	5 %		5 %	5 %
PN 4 Increasing crop water productivity in the Victoria Nile basin using stress-tolerant maize and bean varieties in conservation agriculture systems	60%	20%		10%	10%
PN 18 Sustainable management of tree-based systems in East African highlands through bottom-up research and development interventions	10%	70%		20%	
PN 19 Improved water and land management in the Ethiopian highlands and its impact on downstream stakeholders dependent on the Blue Nile	10%	45%		30%	15%
PN 20* Sustaining inclusive collective action that links across economic and ecological scales in upper watersheds (SCALES)		50%		25%	25%
PN 21 Ensuring benefits for those who need them most: Building strong institutions for managing inclusive multi-stakeholder processes for watershed development	10%	70%	5 %	10%	5 %
PN 22* Payment for environmental services as a mechanism for promoting rural development in the upper watersheds of the tropics	5 %	60%		18%	17%
PN 31 Integrated land-water management and fish yield sustainability: Lake Kyoga and its basin	10%	20%	40%	20%	10%
PN 32 Enhancing diverse wetland benefits in the Upper Nile and Volta basins through integrated catchment management		30%	40%	30%	
PN 34* Improved fisheries productivity and management in tropical reservoirs	5 %	10%	70%	10%	5 %
PN 36* Improved planning of large dam operation: Using decision-support systems to optimize livelihood benefits, safeguard health and protect the environment			20%	80%	
PN 37* Increasing water-use efficiency for food production through better livestock management: The Nile river basin	30%	20%		50%	
PN 53* Food and water security under global change: developing adaptive capacity with a focus on rural Africa			100%		

Sao Francisco

Here are the basin priorities and research agenda for the Sao Francisco.

Basin priorities emphasize fisheries and aquatic resources management, with some attention given to irrigated and rainfed agriculture, and to questions of governance. Approved projects for this basin place a greater emphasis on crop water productivity, pollution, and decision support.

Basin Priorities

Improvement of management and use of water in irrigation areas with water shortage and/ or salinity problems (Theme 1)

Management of flood and drought risks (Themes 2 and 4)

Developing decision-support tools for improving water productivity by integrating fisheries enhancement in water-congested, flooded and flood-prone areas and non-traditional areas (Theme 3)

Developing tools for measuring water productivity that include fisheries and aquaculture (Theme 3)

Development of governance systems that foster equitable and sustainable management of aquatic resource systems (Themes 3 and 5)

Development of sustainable production systems to improve livelihoods in areas with low and erratic rainfall (Theme 4)

Research agenda

Projects	Theme 1- Crop water productivity improvement	Theme 2- Water and people in catchments	Theme 3- Aquatic ecosystems and fisheries	Theme 4- Integrated basin water management systems	Theme 5- Global and national water and food systems
PN 13 Developing cereal and pulse cultivars for sustainable cropping systems, increased food security and community well-being in the São Francisco basin	75%	10%			15%
PN 14 Improving water productivity and assessing agricultural-induced environmental problems in the São Francisco river basin	45%	15%		30%	10%
PN 45 Agricultural management of water resources through modeling to enhance food security and sustainable development in the Paracatu basin	20%	5 %		60%	15%
PN 46* Planning and evaluating ensembles of small, multipurpose reservoirs for the improvement of smallholder livelihoods and food security: Tools and procedures		25%	15%	50%	10%

Volta

Here are the basin priorities and research agenda for the Volta.

As is suitable for a basin located in a dry area, priorities emphasize livelihoods improvement in rainfed, drought-prone areas as well as groundwater irrigation. Basin priorities also focus on externalities and trade-offs, transboundary water sharing, investment analysis, and the broad area of “governance”. Little is specifically said about catchment management.

Approved projects for the basin do have a suitable focus on crop water productivity in dry areas. There are also several projects focusing on modeling for decision-support for governance structures. Projects place a greater emphasis on catchment management than suggested by the priorities, and two projects have a very specific focus on the use of wastewater for irrigation of vegetables in peri-urban agriculture.

Basin Priorities

Development of sustainable production systems to improve livelihoods in areas with low and erratic rainfall (Theme 4)

Upstream-downstream conflicts: trade-offs and environmental externalities of catchment management (Theme 2)

Development of governance systems that foster equitable and sustainable management of aquatic resource systems (Themes 3 and 5)

Policies and management strategies for sustainable groundwater irrigation (Themes 4 and 5)

Role of public and private sector investments to optimize allocation within the agricultural sector and optimal investments in water use sectors vs. other kinds of investments in poverty alleviation (Theme 5)

Institutional mechanisms for improved water management including market-oriented approaches in transboundary water sharing, water pricing, and user rights (Theme 5)

Research agenda

Projects	Theme 1- Crop water productivity improvement	Theme2- Water and people in catchments	Theme 3- Aquatic ecosystems and fisheries	Theme 4- Integrated basin water management systems	Theme 5- Global and national water and food systems
PN 5* Enhancing rainwater and nutrient-use efficiency for improved crop productivity, farm income and rural livelihoods in the Volta basin	50%	10%		30%	10%
PN 6* Empowering farming communities in Northern Ghana with strategic innovations and productive resources in dryland farming	70%	10%	15%		5 %
PN 27 Forests, water and land-use mosaics: Catalyzing change in upper catchments		60%		20%	20%
PN 32 Enhancing diverse wetland benefits in the Upper Nile and Volta basins through integrated catchment management		30%	40%	30%	
PN 34* Improved fisheries productivity and management in tropical reservoirs	5 %	10%	70%	10%	5 %
PN 38* Safeguarding public health concerns, livelihoods and productivity in wastewater irrigated urban and peri-urban vegetable farming in Ghana				100%	
PN 39 Decision support for agricultural investment strategies in the Volta basin with special reference to informal smallholder irrigation	10%	20%		45%	25%
PN 40* Integrating knowledge from computational modeling with multi-stakeholder governance: Towards more secure livelihoods through improved tools for integrated river basin management		40%		50%	10%
PN 46* Planning and evaluating ensembles of small, multipurpose reservoirs for the improvement of smallholder livelihoods and food security: Tools and procedures		25%	15%	50%	10%
PN 47* Transboundary water governance for agricultural and economic growth and improved livelihoods in the Limpopo and Volta basins: Towards African indigenous models of governance	10%	10%	5 %	40%	40%
PN 51* The impact of waste water irrigation on human health and food safety among urban communities in the Volta Basin – opportunities and risks	20%			80%	

Yellow

Here are the agenda priorities and research agenda for the Yellow River basin.

There is a long list of basin priorities, vs. a relatively short list of approved projects. Basin priorities focus on irrigation water management, including groundwater, and downstream consequences of upstream water use practices. This latter point appears in specific priorities related to upstream – downstream conflicts and degradation of aquatic ecosystems. There is a surprisingly heavy emphasis on fisheries and aquatic ecosystems.

In contrast, approved projects place a heavy emphasis on crop water productivity improvements in ways to reduce erosion and pollution. Although there are some projects that focus on governance, in general projects do not cover the area of fisheries.

Basin Priorities

Improvement of management and use of water in irrigation areas with water shortage and/ or salinity problems (Theme 1)

Decision support tools for holistic management of aquatic resources at basin scale (Theme 2)

Upstream-downstream conflicts: trade-offs and environmental externalities of catchment management (Theme 2)

Developing decision-support tools for improving water productivity by integrating fisheries enhancement in water-congested, flooded and flood-prone areas and non-traditional areas (Theme 3)

Social and economic costs of degradation of aquatic ecosystems (Theme 3)

Policies and management strategies for sustainable groundwater irrigation (Themes 4 and 5)

Institutional mechanisms for improved water management including market-oriented approaches in transboundary water sharing, water pricing, and user rights (Theme 5)

Rights and access to water by the poor, women and socially excluded groups in the process of global change (Theme 5)

Development of governance systems that foster equitable and sustainable management of aquatic resource systems (Themes 3 and 5)

Research agenda

Projects	Theme 1- Crop water productivity improvement	Theme 2- Water and people in catchments	Theme 3- Aquatic ecosystems and fisheries	Theme 4- Integrated basin water management systems	Theme 5- Global and national water and food systems
PN 12* Conservation agriculture for the dry-land areas of the Yellow river basin: Increasing the productivity, sustainability, equity and water use efficiency of dryland agriculture, while protecting downstream water users	60%	25%		10%	5 %
PN 16* Developing a System of Temperate and Tropical Aerobic Rice (STAR) in Asia	100%				
PN 21 Ensuring benefits for those who need them most: Building strong institutions for managing inclusive multi-stakeholder processes for watershed development	10%	70%	5 %	10%	5 %
PN 26 An integrated analysis of the impact of current and planned re-vegetation on the food security, hydrology, and sedimentation in the Yellow river basin		60%		20%	20%
PN 42* Groundwater governance in Asia: Capacity building through action research in the IGB and the Yellow river basin (YRB)	10%	5 %		50%	35%
PN 43 Water allocation in the Yellow river: Balancing water withdrawals and ecological water requirements for food security and environmental sustainability				70%	30%
PN 44 Mitigating water stress in the Yellow river basin: Strategies for agricultural water savings and improved water productivity	40%		20%	40%	

Concluding remarks

CPWF research aims to help solve problems of poverty, food security, health and environment in selected basins by fostering the development and adoption of water-related interventions, in particular those that improve water productivity. At the moment, the “water-related interventions” in question are those listed as outputs from the 50 projects approved as part of the first call by the CPWF for competitive grant proposals.

It was noted earlier that the selection of research priorities normally is influenced by the importance and incidence of a problem, the likelihood of solving it, the level of investment required, the time period over which adoption of a problem-solving intervention is expected to unfold, and the discount rate used to convert future costs and benefits into present values. One implication is that the approved projects are those that address relatively important problems and that are most likely to be successful in finding solutions that benefit many people over large areas in a reasonable time frame. That is, the approved projects are those most likely to result in desirable impacts.

Confirmation on whether or not this happens will depend on monitoring, evaluation, and impact assessment. Assessing impacts for many of the approved projects will be enormously difficult, however, either because quantification of benefits will be challenging, or because it will be difficult to establish causality between research activities and developmental outcomes. For example, it can be quite difficult to detect notable changes in downstream aquatic ecosystems and then trace these changes to specific upstream investments in water management.

CPWF is aware of this impact assessment issue and will work toward the development of protocols that will be up to the task. One early step in this

direction will be to further clarify for approved projects the relationship between research activities/ outcomes and the development problems of interest. As research planning and monitoring proceed, CPWF partners will describe more systematically the mechanisms whereby research in approved projects will contribute to poverty reduction, and improvements in food security and health.

In the Andean system of basins, for example, priority is given to institutional and policy interventions aimed at influencing stakeholder rights so that poor people in upper catchments receive benefits from upstream investments made to improve downstream water quality. Let’s assume that an institutional mechanism is put in place whereby downstream water users compensate upstream farmers for investments aimed at improving upstream water productivity and reducing downstream pollution. In which practices will upstream farmers invest? Specific technologies will still need to be developed, and adapted to local circumstances, and impacts on downstream water quality will need to be monitored.

As another example, a priority sometimes has been given to “decision support tools for holistic management of aquatic resources at basin scale.” Some assessment will be needed in selected basins as to who uses these tools, which decisions are influenced by these tools, and whether decisions are different – because of these tools – than would otherwise be the case.

Given that many of the approved projects aim to generate knowledge, it will be important to show how this knowledge is used, by whom, and through what mechanisms, such that poverty, food security, health and environment problems are aggressively and truly addressed.

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