CGIAR
Challenge Program on
Water and Food

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

Synthesis 2005

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CGIAR Challenge Program on
WATER & FOOD

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Suggested Citation:
Harrington, Larry et al 2006. Synthesis 2005.Challenge Program on Water and Food, Colombo, Sri Lanka.

CGIAR
Challenge Program
on Water and Food

A synthesis report of activities and accomplishments of the CGIAR Challenge Program on Water and Food - 2005

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Executive summary

Water scarcity is one of the most pressing issues facing humanity today. Human prosperity and health depend on access to adequate water. However, the availability and quality of water resources are highly variable around the world. As global population and urbanization increase, competition for water becomes more intense. To meet these needs, more food must be produced using less water.

The CGIAR Challenge Program on Water and Food (CPWF) has taken on this challenge from a research perspective. CPWF is an international, multi-institutional research initiative with a strong emphasis on north-south and south-south partnerships. The initiative brings together research scientists, development specialists, and river basin communities in Africa, Asia and Latin America to create and disseminate international public goods (IPGs) that improve the productivity of water in river basins in ways that are pro-poor, gender equitable and environmentally sustainable.

The purpose of this report is to contribute to a synthesis of CPWF activities and achievements through the end of 2005, with an emphasis on the 33 first-call competitive grant projects. The notion of synthesis suggests a process of combining separate elements, thoughts, ideas, or information to form a coherent whole. In the context of the CPWF, synthesis research seeks to help make sense of the large body of dispersed data and information that accumulates over time, and to package it in ways that meet the needs of different users. The very fact that the CPWF research agenda is implemented through distinct projects, in multiple basins, with varying levels of emphasis on five different Themes, underscores the importance of a conscious and systematic approach to synthesis.

The CPWF conducts most of its research on water and food in benchmark basins, organized around five different Themes. Nine benchmark river basins have been selected that present diverse biophysical, socioeconomic and institutional settings. These are the Andes system of basins, and the Indus-Ganges, Karkheh, Limpopo, Mekong, Nile, São Francisco, Volta and Yellow river basins. The selected basins cover Africa, Asia and Latin America.

CPWF Themes are a means for addressing different aspects of the water and food challenge and serve to package information at different scales on issues related to water productivity. Theme leaders lead collaborative efforts to understand how the main drivers affecting water and food security evolve over time, and how changes in these drivers will affect future water and food security. The five Themes are crop water productivity improvement, water and people in catchments, aquatic ecosystems and fisheries, integrated basin water management systems, and Global and national water and food systems

This particular synthesis document is organized by Theme. Each Thematic section begins with a review of the importance and significance of the Theme being discussed, and a listing of relevant research areas and key questions. Research areas and key questions were identified and listed "*ex ante*" during initial CPWF planning, prior to the approval of the specific project portfolio for the Theme. An "*ex post*" assessment is then made of the set of (approved and funded) projects relating to the Theme, including an appraisal of the extent to which projects contemplate the identified research areas and key questions. After this, the specific problems or issues that projects aim to address are identified, and interrelationships among key questions, research areas and issues are discussed.

Projects assigned to the Theme are examined with regard to objectives, approaches, achievements, and status. Cross-basin and cross-Theme implications are noted, along with opportunities for fruitful collaboration or dialogue across projects. There are many instances in which CPWF projects build on the accomplishments of earlier non-CPWF research. As long as the earlier research is

properly recognized, such a strategy seems to represent a wise use of scarce resources. By building on past success, the CPWF can greatly increase the efficiency with which it uses its limited resources.

The CPWF is most concerned with the large numbers of the very poor in developing countries. In these countries, 70-90% of water is consumed in agricultural production. Water is also needed, however, for rural and urban domestic use, industrial use, power generation, river transport, fish production, and the preservation of wildlife habitat and ecological processes. Despite rapid urbanization, the rural population in the poorest countries will continue to increase, and put additional pressure on the natural resource base. One way to meet these competing needs is to increase water productivity, especially in agriculture. More food must be produced using less water.

Such problems are not quickly solved and the CPWF itself is relatively young. During its brief history, then, what have been its major achievements? The CP has achieved success in four distinct areas: vision and design, program implementation, and on-the-ground impacts.

Vision and design

The vision of the CPWF is an ambitious one of partnership-based research for development that generates favorable impacts at the largest possible scale. It does this by:

- Focusing on some of the developing world's largest and most important river basins (e.g., Indus-Ganges, Mekong, Nile, Yellow)
- Studying these basins at all scales of analysis (plant, field, agroecosystem, catchment, sub-basin, whole basin, national, global)
- Taking account of all landtypes found in these basins (upper catchments, dryland and humid rainfed agricultural areas, irrigated agricultural areas, urban areas, coastal areas, inland and coastal fisheries, environmentally-sensitive areas)
- Incorporating a wide range of tools and approaches (plant breeding, crop management, landscape and agroecosystem management, trade-off analysis, institutional analysis, stronger governance and decision-support in water resource allocation and investment., scenario analysis)
- Identifying highly innovative topics for research (e.g., livestock water productivity, aerobic rice systems, payments for environmental services, the downstream consequences of upstream interventions, integrated strategies for dryland areas combining drought-tolerant varieties and rainwater harvesting practices).

Program implementation

As befits a CGIAR Challenge Program, the CPWF has welcomed a wide range of stakeholders and partners in accord with their ability to help achieve Program goals. Decisions on research investments (project selection) have been based on a competitive grants process in which proposal quality was evaluated by an independent external panel. The usual weakness of a competitive grants approach – lack of coherence in the research agenda – has been addressed through Basin Focal Projects and synthesis research.

Technologies, policies, and information

In describing on-the-ground impacts, it is important to keep a sense of perspective. This synthesis describes CPWF progress through the end of 2005 – but of all the projects described in the above sections, only 18 were approved and funded before January 1, 2005. The following discussion largely focuses on those 18 projects.

CPWF project achievements include progress in the development of technologies, policies and information. Some relate specifically to irrigated, high-rainfall, or dryland environments. Others have relevance across environments.

Major achievements for irrigated environments include:

Progress in the development of aerobic rice germplasm and accompanying management practices, to produce more rice while using far less water than required with puddling.

Advances in the development of salt-tolerant germplasm for rice, wheat, barley and mustard, to make more effective use of salt-affected irrigated areas. Specific advances have been made in the mapping of QTLs for salinity tolerance in rice.

Progress in formulating strategies for dealing with seawater incursion into rivers, including:

- Water management technologies that reduce or eliminate the harm done to crops by saltwater intrusion.
- Technologies that transform saltwater intrusion from a problem into an opportunity (e.g., the introduction of rice-fish and shrimp poly-culture).
- The development or improvement of simulation models to underpin decision-support systems for water allocation and use in the context of conflicting stakeholder needs in complex coastal environments.

Investments in the construction of community-level dugouts or reservoirs to store water for small irrigation and fish production, and house-hold water storage reservoirs to allow farm families to more readily engage in income-related crop and food processing.

An improved understanding of how to use wastewater in irrigated peri-urban vegetable production, in ways that result in products that are safe and nutritious for consumers.

Major achievements for high-rainfall environments include:

Progress in understanding and further developing "slash and mulch" practices for hillside agroecosystems, and targeting their dissemination as a replacement for "slash and burn" practices.

Advances in the development of conservation agriculture practices, and accompanying farm implements, for direct sowing into crop residues without tillage. This is accompanied by a better understanding of the consequences of these practices for erosion control and downstream water quality.

Major achievements for dryland environments include:

Progress in the development and dissemination (through participatory varietal selection and seed production schemes) of drought-tolerant varieties of sorghum, barley, wheat, chickpea, lentil, faba bean, and cowpea.

Improved understanding (through GIS/ agroecological zoning) of target areas for the dissemination of drought-tolerant varieties and production of breeder seed.

Advances in understanding livelihood vulnerability and resilience, and farmer's innovations, in dry areas.

Important steps towards a conceptual framework for understanding and improving livestock water productivity.

Progress in tailoring combinations of water harvesting systems and fertilizer micro-dosing to specific dryland locations, and in understanding the performance and associated risk of these practices.

Advances in understanding and managing ensembles of small reservoirs in dry areas. This includes a better understanding of how changes in the management of an upstream reservoir can impact water availability in downstream reservoirs.

Steps forward in formulating guidelines for the utilization of scarce wetlands in dry environments. This involves the development of simulation models for use in analyzing trade-offs among alternative mixtures of agricultural (crop and livestock) and fisheries water-use strategies in wetlands.

Major achievements across environments include:

Progress in the global dissemination of multiple-use water systems, through Learning Alliances.

Steps forward in learning how to strengthen multi-stakeholder governance structures by identifying problems, shaping policy options, and establishing criteria for their evaluation by stakeholders, where stakeholder evaluation of options is assisted by a simulation model capable of predicting agent-agent and agent-environment interactions.

An improved understanding of indigenous water use institutions and regulations in Africa, culminating in the publishing of a database of African water laws. This is done with an eye to identifying indigenous approaches to transboundary water governance.

A deeper understanding of how collective action can be used by people living in catchments can

help them escape from poverty. Basic to this is an improved understanding of the dynamic biophysical, social and political interactions that take place across different watershed scales.

Advances (through a CPWF-organized workshop) in understanding the implications of globalization and trade on water and food security, including:

- The likely effects on water use and food security in developing countries of the WTO (and in particular the GATS and the liberalization of trade in environmental goods)
- The large effect on water and food in developing countries from non-water sector liberalization (e.g., foreign direct investment agreements in the industrial or agricultural sectors).

Synthesis has also identified several opportunities where it may be possible for the CPWF to improve coherence, increase research efficiency, and accelerate progress towards achieving its development goals. These include-

Encouraging cross-project learning on ways to improve crop water productivity in relatively dry rainfed environments.

Harnessing more effectively lessons learned on improving crop water productivity in relatively wet rainfed environments.

Taking a broader approach to the development of aerobic rice systems.

Strengthening agroecological zoning and site similarity analysis for scaling out.

Fostering closer links between research on salt-affected areas and on groundwater governance.

Developing a cross-basin community of practice on water resource governance and decision-support.

Examining the basin-level consequences of farm-level interventions in irrigated areas.

Conduct ex-ante analysis on the anticipated pay-offs from different kinds of investments in different Themes and basins.

Introduction

The Challenge Program on Water and Food

Water scarcity is one of the most pressing issues facing humanity today. Human prosperity and health depend on access to adequate water. However, the availability and quality of water resources are highly variable around the world. Typically, the most extreme shortages are felt by those least able to cope with them – the very poor living in developing countries.

In these countries, agriculture accounts for 70 – 90% of water use. Water is also essential, however, 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. To meet these needs, more food must be produced using less water.

The CGIAR Challenge Program on Water and Food (CPWF) has taken on this challenge from a research perspective. CPWF is an international, multi-institutional research initiative with a strong emphasis on north-south and south-south partnerships. The initiative brings together research scientists, development specialists, and river basin communities in Africa, Asia and Latin America to create and disseminate international public goods (IPGs) that improve the productivity of water in river basins in ways that are pro-poor, gender equitable and environmentally sustainable.

CPWF practices research for development. Ongoing research work exemplifies this emphasis, and illustrates the Challenge Program's mix of site-specificity, scaling up to the basin level, and the production of international public goods. Thus, CPWF funds and conducts research that is a mixture of basic, applied and adaptive research linked to dissemination of results.

The Challenge Program is working towards achieving: food security for all at household level; poverty alleviation through increased sustainable livelihoods in rural and peri-urban areas; better health through improved food security, lower agriculture–related pollution and reduced water-related diseases; and environmental security through improved water quality as well as maintenance of water-related ecosystems and biodiversity.

Research Activities

The CPWF conducts most of its research on water and food in nine benchmark basins, organized around five different Themes. Most CPWF work is implemented through "first call projects", "basin focal projects", "small grant programs" and "synthesis activities".

First call projects: The greater part of the CPWF research agenda is implemented through specific projects that were evaluated and selected through a competitive grant process. CPWF's first call for project proposals yielded a portfolio of 50 high quality projects, of which, 33 currently receive funding. This report seeks to synthesize the outcomes of these 33 projects through the end of year 2005.

Small grant programs: These projects aim to identify existing small-scale or local-level water and/ or agricultural management strategies or technologies that have the potential to improve agricultural water productivity at some wider scale.

Basin focal projects: The BFPs add value to individual research project outputs, and yield knowledge about water poverty and water productivity at the basin level. Because they are

relatively new, neither BFPs nor small grant projects are included in the present synthesis.

Synthesis: The Challenge Program on Water and Food deals with complex, diverse and dynamic systems for which there are a growing number of stakeholders generating information. Synthesis research is needed to make sense of the large body of dispersed and disciplinary literature and data that accumulates over time, and to package it in ways that meet the needs of different users. This report is one example of CPWF synthesis research.

Water productivity

Within the CPWF, a central concept is that of water productivity. Most projects, Themes and basins use this concept in one way or another. In the context of agriculture, water productivity is defined as agricultural output per unit of water depleted. Crop water productivity is a measure of the ratio of crop outputs and services per unit volume of water depleted. Similarly, livestock water productivity is the ratio of livestock outputs and services per unit volume of water depleted. Crop and livestock outputs and services can be measured in value terms when water has multiple uses. Water depletion is estimated in similar ways regardless of whether the water is used in crop production, livestock or fisheries production, or urban and industrial use. In all cases, the amount of water depleted is that made unavailable for reuse, e.g., through evaporation, contamination or flow to a saline sink.

Benchmark basins

The CPWF believes that research to address issues of water productivity is best conducted in the context of an entire river basin. How water is managed within a 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 interrelate. 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.

Nine benchmark river basins have been selected that present diverse biophysical, socioeconomic and institutional settings. These are the Andes system of basins, and the Indus-Ganges, Karkheh, Limpopo, Mekong, Nile, São Francisco, Volta and Yellow river basins. 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 large populations of poor people 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.

Themes

CPWF Themes are a means for addressing different aspects of the water and food challenge and serve to package information at different scales on issues related to water productivity. The CPWF Research Strategy concentrates its attention on five thematic areas, each one led by a specialist from a different CGIAR center. Theme leaders lead collaborative efforts to understand how the main drivers affecting water and food security evolve over time, and how changes in these drivers will affect future water and food security. The five Themes are:

Theme 1: Crop water productivity improvement

This Theme takes the view that water productivity can be improved through technological and managerial innovation at the farm level. Hence it

seeks plant-breeding solutions for agriculture located in areas affected by drought and saline soils. It studies integrated natural resources management and crop production at field, farm and agro-ecosystem levels. Work within this Theme also examines and promotes policies and institutions facilitating the adoption of crop water productivity improvements.

Theme 2: Water and people in catchments

This Theme focuses attention on the multiple ways that people manage water between the plot and the basin scale. Formal or informal institutions often exist for the governance of springs, streams, ponds, wetlands, potable water systems, and other water resources. In many instances, there are opportunities for improving their equity and efficiency. At times, institutions may not be in place to "internalize" important "externalities", e.g., when upstream land and water management practices affect people downstream. Theme 2 seeks to identify institutional and technological innovations that improve people's capacity to manage water collectively, with special attention paid to ensuring that the needs of women and the poor are not overlooked in the process.

Theme 3: Aquatic ecosystems and fisheries

Aquatic environments are a key source of nutrition for many of the world's poor – often, they are the sole source of protein for these communities. Research under this Theme investigates environmental water requirements; to value ecosystem goods and services; and to seek innovative ways in which to improve the productivity of aquatic ecosystems through policies, institutions, and governance.

Theme 4: Integrated basin water management systems

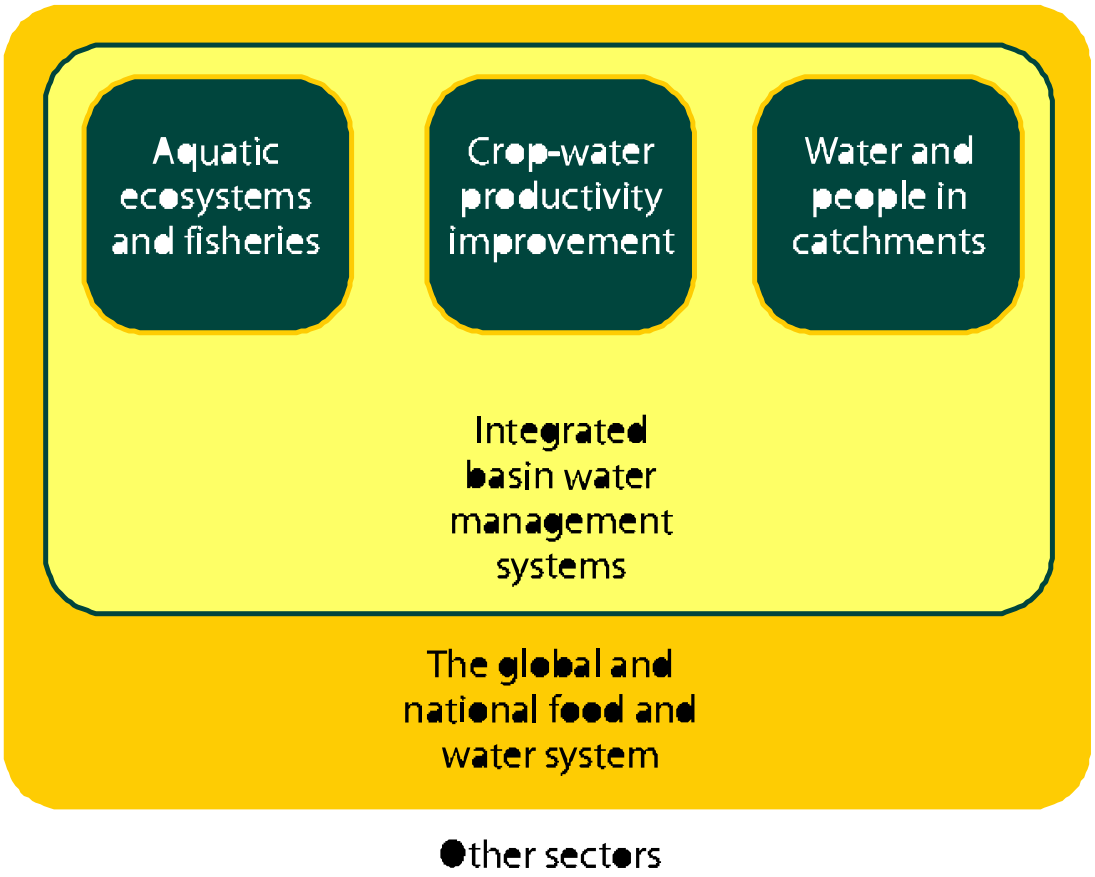
Increasingly, integrated water resources management (IWRM) is viewed as a promising strategy for managing water resources. This Theme identifies appropriate technologies and management practices designed to enable IWRM. It seeks innovative institutional arrangements and decision-support tools and information that can help with the establishment of this managerial strategy.

Theme 5: Global and national water and food systems

Global processes – including globalization, trade, macroeconomic and sectoral policies, as well as global climate change – all have an important bearing on water quantity and quality, availability across various international, national, sectoral, household and gender lines, how it is used, and its productivity. This Theme concerns itself with the kinds of investments and financing for agricultural water development and water supply that may improve water productivity or, indeed, hinder it. This Theme area also recognizes that transboundary issues, whether defined in classical terms of national boundaries, or in increasingly important boundaries of sectors and sub-national boundaries, renders the management of water resources more and more complex and therefore seeks to understand how best to formulate appropriate policy and institutions to deal with this complexity. The Theme also considers changes in the global water cycle with a focus on adaptation strategies to climate change.

Relationships among the five CPWF Themes are shown in Figure 1.

Figure 1: Relationships among the five CPWF Themes



Projects

This report brings together information on the activities and achievements of the 33 first-call competitive grant projects. Each project is clearly linked to one or more benchmark basins and Themes. These linkages were identified during the process of proposal development and approval. Some projects concentrate on cross-basin or cross-Theme research.

The distribution of projects across Themes and basins (Table 1) is somewhat uneven, with a few Themes or basins having more projects than the others. To a certain extent this is unavoidable. In a competitive grant process, proposal quality counts for much. Basins for which a relatively large number of high quality proposals are submitted are likely to have more projects approved. The challenge for CP management has been to maintain a balance of research across basins, and coherence of effort within basins – while simultaneously accepting and funding only the highest quality proposals.

The complete title of each project, along with its respective basin and Theme assignments, is provided in Annex 1.

Table 1: Distribution of CPWF first-call projects across basins and Themes[1]

	Theme 1	Theme 2	Theme 3	Theme 4	Theme 5
Andes		PN20, PN22, PN28, PN40		PN40	PN20
Indus-Ganges	PN7, PN10, PN16	PN28	PN10, PN34, PN35	PN42	PN42, PN48
Limpopo	PN1	PN17, PN28, PN30	PN30	PN17, PN30, PN46, PN47	PN47
Karkheh	PN8	PN24			
Mekong	PN7, PN10, PN11, PN16	PN11, PN25, PN28	PN10, PN35, PN52	PN50	PN50
Nile	PN2, PN7	PN20, PN22, PN28	PN34	PN36, PN37	PN20, PN53
São Francisco				PN46	
Volta	PN5, PN6	PN40	PN34	PN5, PN38, PN40, PN46, PN47, PN51	PN47
Yellow	PN12, PN16			PN42	PN42

Capacity-building and communication

CPWF projects do more than just conduct research. They also serve as platforms for capacity-building among project partners and stakeholders. Capacity-building covers a wide range of activities, including workshops for information exchange, short training courses, opportunities for learning through hands-on collaborative research and even support for formal course-work and thesis research by students. Related to capacity-building are the questions of communication and communities of practice. CPWF Theme Leaders and Basin Coordinators, along with the CP coordination unit, work with project coordinators to foster communication within and among projects. In some cases, “communities of practice” with common areas of interest have spontaneously emerged. This particular synthesis document, however, focuses on research for development, not capacity-building.

The synthesis process

The notion of synthesis suggests a process of combining separate elements, thoughts, ideas, or information to form a coherent whole. In the context of the CPWF, synthesis research seeks to help make sense of the large body of dispersed data and information that accumulates over time, and to package it in ways that meet the needs of different users. The very fact that the CPWF research agenda is implemented through distinct projects, in multiple basins, with varying levels of emphasis on five different Themes, underscores the importance of a conscious and systematic approach to synthesis.

[1] See Annex 1 for full project titles and basin/ Theme assignments.

This particular synthesis document is organized by Theme. Each Thematic section begins with a review of the importance and significance of the Theme being discussed, and a listing of relevant research areas and key questions. Research areas and key questions were identified and listed "*ex ante*" during initial CPWF planning, prior to the approval of the specific project portfolio for the Theme.

An "*ex post*" assessment is then made of the set of (approved and funded) projects relating to the Theme, including an appraisal of the extent to which projects contemplate the identified research areas and key questions. After this, the specific problems or issues that projects aim to address are identified, and interrelationships among key questions, research areas and issues are discussed.

Projects assigned to the Theme are examined with regard to objectives, approaches, achievements, and status. Cross-basin and cross-Theme implications are noted, along with opportunities for fruitful collaboration or dialogue across projects. The time frame for the above analysis extends through the end of 2005.

The synthesis finishes with a discussion of the coherence of basin-level project portfolios, capacity-building, and principal CPWF achievements and challenges as of late 2005.[2]

[2] The present synthesis does not attempt to evaluate the quality of research conducted by any particular project, nor does it aim to draw conclusions on the suitability of any particular technology or policy intervention.

Theme 1 – Crop water productivity improvement

For poor farm families, crop production serves many purposes. It provides food for the farm household, cash from the sale of marketable commodities, fodder and feed for livestock, organic residues and green manures to enrich and protect soils, and employment for family members. Food security, farm family health and crop production tend to be closely linked, and the interventions used to achieve increased crop production typically have some effect on the quality of land and water resources. Crop production is frequently the single most important source of employment in rural areas. The resulting incomes allow farmers and landless laborers to buy goods and services, thereby generating further employment elsewhere in the economy.

In areas where populations are growing rapidly, agricultural and non-agricultural sectors increasingly compete for water supplies. Improvements in crop water productivity make possible an expansion in crop production without a corresponding increase in water use. Theme 1 focuses on farming methods that boost "crop per drop" and thereby enhance food security and livelihoods while keeping water diverted for agriculture at year 2000 levels.

There is a strong emphasis within this Theme on improving crop water productivity by dealing effectively with drought, floods, salinity, and other abiotic stresses. Means for achieving this include crop genetic improvement for stress tolerance, crop and agroecosystem management, landscape management, and supporting policies. Ultimately, work associated with Theme 1 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.

CPWF Theme 1 participants and stakeholders have developed a conceptual framework for the improvement of crop water productivity. This framework features four principles: higher crop yields, larger flows into water storage pools, smaller flows out of these storage pools, and larger storage pool size. These four principles are portrayed in more detail in Figure 2.

Research areas, key questions, issues, and projects

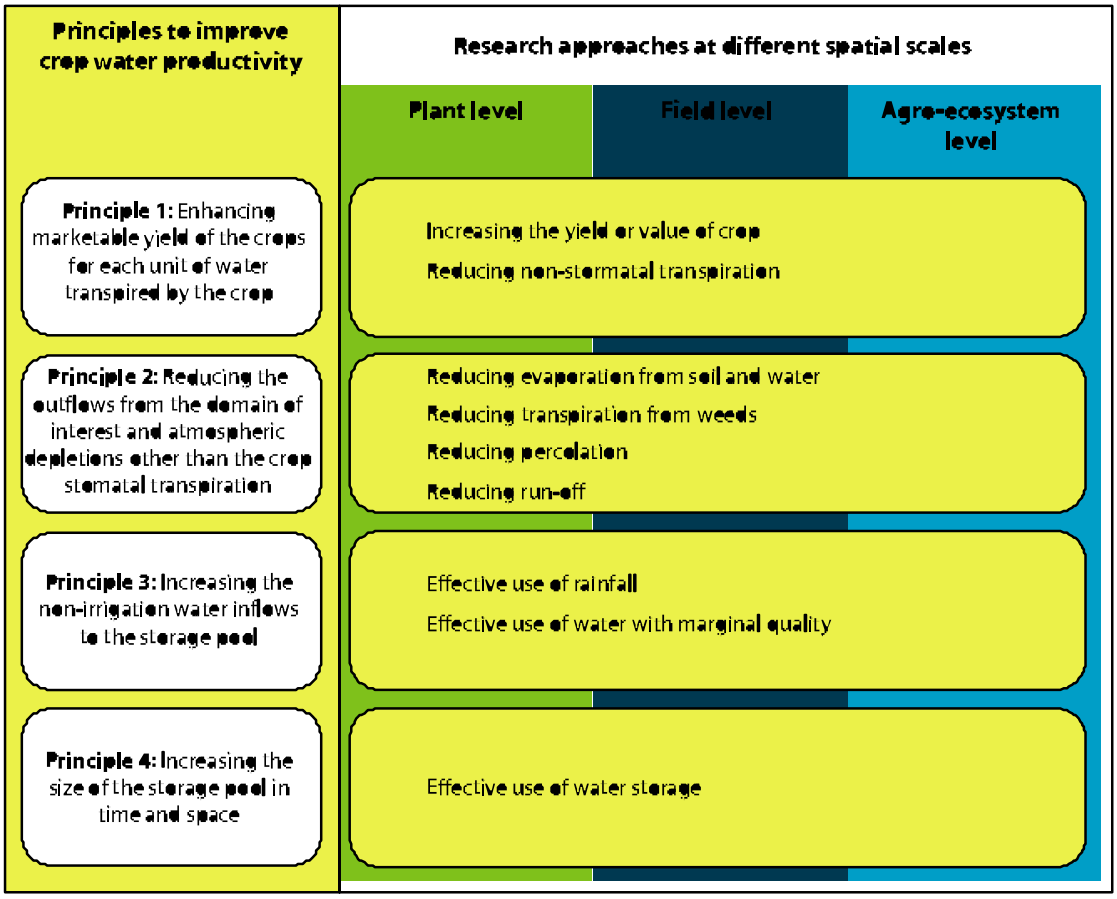
CPWF activity within Theme 1 is implemented through specific projects associated with research areas that were identified during the research planning process. Projects are intended to help answer a number of pre-determined key questions. For the purpose of this synthesis, projects are further grouped according to the issue or problem being addressed. Projects tend to touch on several research areas and address more than one key question, but usually focus on a single issue. Theme 1 research is being conducted in all benchmark basins.

Four research areas, representing ways to operationalize the conceptual framework described above, were identified by Theme 1 participants and stakeholders.

1. *Plant breeding for water-efficient and stress-tolerant crops*, including the development of aerobic rice varieties, and the development of drought tolerant varieties, early-maturing varieties for drought escape and salt-tolerant varieties. Two key questions were identified:
   - To which traits should priority be given in using molecular techniques to increase the efficiency of conventional plant breeding to improve water productivity?
   - How can water productivity be maintained for crops growing under extended periods of mild water deficit or brief periods of severe water deficit?

2. *Water-saving farm practices*, including improved crop-water-nutrient management, crop production risk management technologies (e.g., water harvesting), and the evaluation of crop water productivity using modern tools. Two key questions were posed:

Figure 2: Conceptual framework for the analysis of crop water productivity[3]



- How can advances in information technologies help develop better frameworks to analyze and predict crop water productivity in different environments?
- Which cropping patterns and management practices enhance production and farmers' income without increasing water input?

3. Management of water supply based on field water requirements, including supplementary irrigation, the integration of multiple uses of water and the use of tools and methods for quantifying water quality. Key questions are:

- How can the management of irrigation systems be improved to match water supplies to field water requirements, and to make more effective use of unevenly distributed rainfall and water storages?
- Which sustainable strategies can improve production and water productivity in land that is degraded due to water logging and salinization?

4. Policies and institutions, in particular those that affect farmer adoption of water productivity-enhancing technologies and farm management options. Relevant key questions include:

- What types of policies and institutional arrangements will promote farmer adoption of water productivity-enhancing technologies?
- How can lessons from experiences in participatory research and extension in other areas be applied?

In practice, many projects aiming to improve crop water productivity in particular environments utilize

[3] Source: CPWF. 2005. Theme 1: Crop Water Productivity Improvement 2005 Synthesis Report

a combination of improved varieties, crop and water management practices, land management systems and supporting policies. That is, they apply most or all research areas simultaneously. With this in mind, and for the purposes of synthesis, Theme 1 projects are further grouped according to the following three issues:

1. *Improving crop water productivity in relatively dry rainfed environments (Projects 1, 2, 5, 6, 8, 12, 17)*
2. *Improving crop water productivity in relatively wet rainfed environments (Projects 11, 15)*
3. *Improving crop water productivity in irrigated and salt-affected[4] areas (Projects 7, 10, 16)*

Curiously, different Theme 1 projects have selected very different sets of interventions, even when dealing with similar environments. Some (but not all) of this divergence can be explained by variability in agroclimatic and socioeconomic circumstances across basins. A summary of how research areas relate to issues is provided in Table 2.

Improving crop water productivity in relatively dry rainfed environments

About half of Theme 1 projects focus on rainfed agroecosystems in relatively dry environments. These projects are located in the Limpopo, Karkheh, Nile, Volta and Yellow[5] river basins. Some projects are largely restricted to the development and introduction of new germplasm. Others focus on the development and introduction of new crop, soil, water or nutrient management practices. A few allow for agroecosystem diversification. Several follow an integrated approach, combining new germplasm and crop, soil, water or nutrient management practices. It may be useful to further explore the reasons for this dissimilarity in the selection of interventions and to identify opportunities for fruitful interaction and mutual learning among projects.

The distribution of interventions across Theme 1 projects located in dry rainfed environments is summarized in Table 3.

[4] All salt-affected areas studied in Theme 1 are located in irrigated environments.

[5] There is a rainfall gradient in the Yellow River basin, with Inner Mongolia being drier than Shandong Province. Project reports concentrate on activities at the drier end of this gradient.

Table 2 Distribution of interventions by research area and issue, Theme 1 project s

	Research area				
	Plant breeding for water-efficient and stress-tolerant crops	Water-saving farm practices	Management of water supply based onfield water requirements	Policies and institutions	Other
Improving crop water water productivity in relatively dry rainfed environments	Drought tolerant varieties Early maturing varieties for drought escape direct sowing (conservation agriculture) Sorghum and millet transplanting	Water harvesting through tied ridges, planting pits or half moons Fertilizer micro-dosing Soil cover, no-till, and	Supplementary irrigation Drip irrigation Dugouts for water storage	Policies to foster adoption suitable varietes and other technologies Policy initiatives in rainwater harvesting Farm implement development for conservation agriculture Market linkages Inventory credit systems	System diversification with high value crops and trees
Improving crop water water productivity in relatively wet rainfed environments	Slash and mulch system (soil cover, no-till and direct sowing in hillsides)			Policies to foster adoption of suitable varieties and other technologies and intensification	Rice system diversification
Improving crop water productivity in irrigated areas, including salt-affected areas	Aerobic rice varieties with high yield potential Salt-tolerant varieties	Conjunctive use of low quality groundwater		Irrigation water use and allocation Policies to foster adoption of suitable varieties and other technologies	Rice-shrimp-fish systems

Table 3 Priority interventions in dry rainfed environments, Theme 1 project s

	PN1	PN2	PN5	PN6	PN8	PN12	PN17
	Limpopo	Nile	Volta	Volta	Karkheh	Yellow	Limpopo
Drought-tolerant or early-maturing varieties							
Water harvesting through tied ridges, planting pits or half moons							
Fertilizer micro-dosing							
Soil cover, no-till and direct sowing (conservation agriculture)							
Supplementary irrigation							
Crop diversification – high value crops or trees							
Transplanted sorghum or millet after pre-rainy season crop							
Dugouts/ reservoirs for water storage, fisheries							
Agroecological zone characterization/ baseline surveys							
Crop modeling for risk assessment							
Policies and institutions	Seed production, including breeder seed	Community based seed initiatives	Market linkages inventory credi systemst	Policy initiatives on rainwater harvesting, competing uses for community water resources	(policy initiatives largely for irrigated areas)	Policies to foster public-private sector investment in farm implement development	Policies foster the development of a participatory innovation system

A focus on germplasm

The greatest emphasis on germplasm is found in Project project 2. This project, working in two areas in Eritrea in the Nile basin, features multi-location **farmer participatory varietal** testing of parental lines, segregating populations and breeding lines of barley, wheat, chickpea, lentil, faba bean, cowpea and grass pea under drought stress. Materials are evaluated for yield, yield stability, drought tolerance, early maturity, resistance to pests and diseases, nutritional quality, and other attributes identified by farmers and end-users. The development of complementary crop management practices is also included in the project, as are policy research and capacity building on topics relating to seed stocks, seed security reserves and community-based seed initiatives.

To date the main achievement has been the identification of barley and wheat germplasm accessions that out yield local checks by as much as 2.5 times in barley and 1.4 times in wheat. Future project reports are expected to document the pace and incidence of farmer adoption of improved varieties.

A focus on crop, soil, water or nutrient management

Three Theme 1 projects – 5, 12 and 17 – lay emphasis on crop, soil, water or nutrient management practices. The former project, located in the Volta basin, emphasizes research on water harvesting systems (WHS – tied ridges, half moons, zaï and other planting pit technologies) and soil fertility management (organic amendments, fertilizer micro-dosing – the very precise application of very small amounts of inorganic fertilizer). Most of these practices are well-known in the target countries and some (e.g., the zaï) already have been adopted by large numbers of farmers. Project 5 adds several new elements, however – DSSAT crop models to assess the long-term risk of alternative management practices, and a market-led approach to system diversification.

In the Limpopo basin, project 17 is working on similar problems in similar ways. Diagnostic work in four districts in the Mzingwane Catchment has included a survey on the use of **water harvesting systems**, their interactions with other crop management practices, and their combined effects on water productivity and crop yields. Survey results are being used to understand farmers' WHS, to find opportunities to improve them, and to identify alternative, potentially useful prototype water management technologies.

Interestingly, many suitable practices are already being used somewhere or other in the Mzingwane catchment. These include tied-ridges, pot-holing, basin tillage, mulch ripping, no-till-tied-ridges, off-season weeding, winter tillage and dead level contours with infiltration pits. Retention of crop residues decreases run-off, but is unpopular because farmers prefer to feed residues to livestock. Experimental data shows that WHS combined with small amounts of fertilizer can substantially reduce the risk of crop failure, while fertilizer use plus supplemental irrigation improves transpirational water productivity. Various combinations of WHS, fertilizer and irrigation components can be very effective.

There is, then, no shortage of prototype technologies. The challenge is to foster a process of participatory technology adaptation, supported by local institutions and policies, and based on an IWRM framework. Farmers and other stakeholders can form a dynamic innovation system for tailoring prototype technologies to local environmental and socio-economic circumstances. They can also help assess the extent to which adapted technologies reduce risk, improve yields, or in other ways contribute to improved livelihoods. Project partners can facilitate this process, while concurrently monitoring the impact of technical change on water productivity in catchments, and water availability elsewhere in the basin.

Project 12, located in the **Yellow** River basin, gives prominence to what has come to be known as "conservation agriculture" – a blend of permanent soil cover, zero-tillage with direct sowing, and innovative crop rotations. This project is inspired by the outstanding success of conservation agriculture

in South America, and builds on earlier work by Chinese institutions and ACIAR on conservation agriculture in the Yellow River basin itself.

In 2005, researcher-managed on-farm experiments were established in Inner Mongolia and Ningxia Autonomous Regions and Henan and Shandong Provinces. These experiments examined alternative methods for wheat crop establishment (zero-till, conventional till and, in some instances, permanent bed and furrow systems) and different residue retention strategies. One purpose of these trials was to obtain information on the effect of conservation agriculture practices on soil parameters, e.g., soil water, temperature, bulk density, granule texture, organic matter and chemistry. When such measurements are repeated over time, it becomes possible to quantify the cumulative impact of conservation agriculture on soil quality.

On-farm testing of alternative rotations is being conducted, as are trials to measure soil erosion with vs. without different levels of residues for soil cover. This latter activity is of some importance, given that much of the interest in conservation agriculture for the Yellow River basin lies in its potential to reduce soil erosion in rainfed areas. Descriptive farm surveys are being planned and, given that farm machinery available in China is not entirely suitable for use with conservation agriculture, implement development is also on the agenda.

Focus on integrated approaches

The remaining Theme 1 projects working in relatively dry rainfed environments – projects 1, 6 and 8 – seek to develop an integrated strategy that combines improved varieties with innovations in crop, soil, water or nutrient management.

In the **Limpopo** basin, project 1 combines the further dissemination of available **drought-tolerant varieties** with **seed production** strategies and **water harvesting systems** (WHS). Varietal dissemination features drought-tolerant, early-maturing varieties for groundnuts, sorghum, millet and maize that have already been released and are known to be adapted. Seed strategies feature the production of breeder seed and a role for the private sector. Rainwater harvesting practices include tied ridges, deep trenches, pot holing and zaï pits.

To date, extensive work has been done on agroecological zoning (to guide later work on scaling out) and a baseline survey (to facilitate subsequent impact assessment). Research and development of rainwater harvesting practices is less advanced.

Project 6, in the **Volta** basin, combines several complementary interventions. These include:

- Improvement of **germplasm** for drought tolerance and early maturity, including sorghum lines with "stay-green" characteristics, drought-tolerant cowpea lines (performed by simulating water stress at key sensitive stages of crop growth), and cassava germplasm with "early bulking" characteristics.
- An unusual cropping system consisting of transplanted sorghum or millet preceded by a pre-rainy season crop of early-maturing cowpea. **Transplanting** improves plant stand, reduce Striga incidence, improve drought tolerance, and reduce crop duration.
- Construction of community-level dugouts or reservoirs to store water for small irrigation and fish production, and house-hold water storage **reservoirs** to allow farm family members to more readily engage in income-related crop and food processing.

These practices, when combined, aim to improve food self-reliance, reduce labor requirements for water collection (typically performed by women and children), and diversify sources of income. Crop improvement work is proceeding and studies have been done on the feasibility of reservoir construction. Site characterization and monitoring, and agroecological zoning to guide scaling out, will be performed in the near future.

Finally, in the **Karkheh** basin, project 8 is implementing an ambitious program to improve water productivity both in rainfed and irrigated areas (discussed separately). For rainfed areas, the

project will exploit important opportunities for increasing rainwater productivity through the use of **supplementary irrigation** at critical stages in the crop cycle. This involves mapping areas suitable for supplementary irrigation, and developing complementary wheat, barley and chickpea varieties and associated management practices. So far, research sites have been selected and characterized, agroecological mapping has been performed for the upper basin, and surveys on farmer innovation have been carried out.

Improving crop water productivity in relatively wet rainfed environments

Compared to the very substantial level of activity described above, there is somewhat less work in Theme 1 for relatively wet rainfed environments. Of the two projects pertaining to this domain, project 11 in the Mekong basin received funding much later than most other CPWF projects. It only became active near the end of 2005 and therefore has less progress to report. Planning was conducted during a project inception workshop held in November, 2005. Plans call for activities in specific catchments in Laos, Thailand and Vietnam:

- Land use assessment and resource mapping
- Analysis of the relationships among livelihood strategies, poverty and water availability
- Intensification of highland rice paddy fields (including the introduction of water-saving technologies)
- Identification of innovative community-level water-sharing arrangements
- Introduction of landscape level changes, featuring rice system diversification with fodder, cash crops and perennial crops.

The second project, project 15, is being implemented in Honduras and Nicaragua, not physically within any benchmark basin. However, it is anticipated that lessons learned in this project will have substantial relevance for numerous basins around the world. This project examines what happens when hillside agroecosystems shift from slash-and-burn to **slash-and-mulch** ("Quesungual") practices. Specifically, it looks at no-till planting of maize and related crops on hillsides into a permanent soil cover derived from the slashing of re-grown native forest vegetation. In these systems, field burning is prohibited through community-led collective action. This project shares a number of elements – permanent soil cover and direct sowing with zero tillage – with research on conservation agriculture in project 12. In both cases, a need for erosion control is an important driving factor. In project 15, however, soil cover is based on slashed forest vegetation while in project 12 soil cover comes from crop residues.

So far, project work for project 15 has focused on:

- Characterization to better understand the biological logic of "Quesungual" systems
- Definition of farmer typologies (farm size, income, position in the landscape) to aid in understanding the circumstances that favor adoption
- Farmer-to-farmer exchanges for technology validation and extrapolation
- Assessment of the consequences of adoption with regard to erosion and soil quality, agrobiodiversity conservation, system productivity and other factors.

Improving crop water productivity in irrigated and salt-affected areas

There are four CPWF Theme 1 projects working in irrigated areas. Each one deals with a slightly different set of problems. One project (project 10) concentrates on managing the fresh – saline water interface in the **Indus-Ganges** and **Mekong** basins. Another one (project 7) explores ways (largely through plant breeding) to improve the productivity of salt-affected areas in the Indus-Ganges, **Mekong** and **Nile** basins. A third (project 8) looks into the improvement of crop water productivity in rainfed (discussed separately) and irrigated areas in the **Karkheh** basin–including the management of salt-affected lands. The fourth project (project 16) focuses on plant breeding for the development of aerobic rice, a technology with great potential to improve water productivity in many irrigated systems.

The fresh – saline water interface

There are instances in benchmark basins when saltwater from the sea moves up into the river, at times for a considerable distance. Such intrusion can pose problems for some people (e.g., rice farmers whose dry season rice crops may be harmed) while presenting opportunities for others (e.g., shrimp farmers who can temporarily expand the scale of their operations). CPWF project 10 is examining three ways to deal with such situations.

One way is to develop technologies that reduce or eliminate the harm done to crops by saltwater intrusion. In Batiaghata, Bangladesh, for example, a short duration *Aus* (dry season) rice crop has been successfully introduced by using for irrigation the rain water that has been harvested and then stored in farm canal networks – even while the surrounding river water has temporarily become saline due to sea water incursion. This strategy is facilitated by the development and dissemination among farmers of salinity-indicator kits to determine in-situ farm-level water quality. Salt-tolerant rice varieties developed by CPWF project 7 are also being tested in this area – a good example of a fruitful links among projects.

The other ways – to be discussed in more detail in the context of Theme 3 – are to develop technologies that transform saltwater intrusion from a problem into an opportunity (e.g., the introduction of rice-fish and shrimp poly-culture) or to develop or improve institutions to manage the conflicting interests of different water users.

Salt-tolerant germplasm and agroecosystem management for salt-affected lands

Many crops are sensitive to salt during the reproductive stage. Genes for salt-tolerance can be identified, and salt-tolerant varieties developed to optimize the use of saline water, thereby allow more productive use of lands affected by salinity.

Rice, for example, is sensitive to salinity at its seedling and reproductive stages. Project 7 is helping develop **salt-tolerant cultivars** that pyramid traits relevant to those stages. The physiological basis of salt tolerance in rice seedlings is fairly well understood and key traits have been identified, among them high seedling vigor, salt exclusion, up-regulation of the antioxidant system, and high tissues tolerance. Although these traits are essentially independent, salt-tolerant landraces typically do not combine favorably. There is considerable variation in the extent of expression of particular traits among cultivars, suggesting that the possibility of identifying even better parental lines.

PN7 is conducting further studies to determine the traits and mechanisms useful for rice salt tolerance during the reproductive stage. A major QTL for salinity tolerance, designated “Saltol”, has been mapped on chromosome 1. Two minor QTLs were also mapped on chromosomes 10 and 12. Efforts are now underway to fine-map Saltol to facilitate tagging for use in marker-assisted selection. Other mapping populations are also available and could be used to tag important traits such as salt exclusion and tissue tolerance. Tagging of important QTLs facilitates the incorporation of these traits into popular varieties.

Phenotypic analysis of component traits could unravel the pathways and genes involved; and tagging of these genes will help in combining component traits underlying salinity tolerance. This could sustainably augment the salt tolerance of existing modern varieties beyond the level observed in any of the known salt-tolerant landraces.

A set of salt-tolerant cultivars (rice, wheat, barley, mustard) is being evaluated. In addition, screening protocols have been developed for salt-tolerant groundnut and pigeon pea.

While project 7 focuses on plant breeding for salt-tolerance, project 8 incorporates the **management of salt-affected areas** into a larger effort to improve irrigated crop water productivity in the **Karkheh** basin. Current low levels of water productivity are attributed to land degradation combined with unsuitable cropping patterns, cultivation methods and irrigation management

practices. In some areas soil salinity from water logging is a major problem – despite the fact that surface water quality is reasonably good. The project aims to identify combinations of salt-tolerant varieties, cropping patterns, irrigation schedules, and cultivation and tillage practices capable of increasing water productivity at the farm level. On-farm experiments are underway. Complementary work will be done to improve understanding of the sources and causes of salinity and to evaluate the long-term consequences of new technologies.

Aerobic rice

The "aerobic rice system" is a simple name for what is in effect a complex and revolutionary way of growing rice without puddling. Aerobic rice uses specialized rice cultivars and complementary management practices to achieve very high rice yields – with only 50-70% of the water typically required for puddled rice systems. To date, aerobic rice systems have been recommended for irrigated or rainfed rice-growing areas where water is too scarce or expensive to allow puddled rice cultivation. As water becomes increasingly scarce, however, aerobic rice practices may become more and more important for much larger areas.

Project 16 project activities are being conducted in water-scarce rice production areas in China (Henan), the Philippines (Central Luzon), Laos and northeast Thailand, and India (Indus-Ganges). Suitable aerobic rice varieties have already been identified for northern China (HD502, HD297, HD277) and for the Philippines (Apo, UPLRi5, UPLRi7). Aerobic rice yields of up to 6.6 t ha^{-1} have been recorded in northern China – with farmers and traders indicating that grain quality is good. In the Philippines, aerobic rice yields have reached nearly 6 t ha^{-1}.

The aerobic rice system is still in its infancy. CPWF project 16 focuses on the continuation of germplasm improvement and the development of management packages suitable for temperate and tropical conditions.

Projects and themes

Many CPWF projects address more than one of the five CPWF Themes. That is, they are "assigned" to multiple Themes. All projects described in this section have large assignments to Theme 1 and some of them are assigned exclusively to this Theme. There is some overlap between Theme 1 on the one hand and Themes 2 and 4 on the other, but most Theme 1 projects have relatively low assignments to any other Theme (Table 4).

There are some exceptions. Project 10 addresses crop water productivity in the freshwater – saline water interface by means of: alternative crop management practices (Theme 1) and improved fisheries opportunities and governance structures (Theme 3). Project 11 seeks improved crop water productivity in rainfed rice-based systems in upper catchments through rice system intensification (Theme 1) as well as diversification and landscape level changes (Theme 2). Theme 1 projects with large allocations to other Themes are further discussed in subsequent sections.

Table 4 : Distribution across Themes of project s with a large assignment to Theme 1

Domains and project	*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 sy stem s*	*Theme 5 – The Global food and water system*
Improving crop water productivity in relatively dry rainfed environments (PN1, PN2, PN5, PN6, PN8, PN12, P17)					
PN1: Increased food security and income in the Limpopo basin through integrated crop, water and soil fertility options and public-private partnerships	70%	20%		10%	
PN2: Improving water productivity of cereals and food legumes in the Atbara river basin of Eritrea	85%	5%		5%	5%
PN5: Enhancing rainwater and nutrient-use efficiency for improved crop productivityfarm income and rural livelihoods in the V olta basin	50%	10%		30%	10%
PN6: Empowering farming communities in Northern Ghana with strategic innovations and productive resources in dryland farming	70%	10%	15%		5%
PN8: Improving on-farm agricultural water productivity in the Karkheh river basin	60%	20%		10%	10%
PN12: 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 users	60%	25%		10%	5%
PN17: 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%	
Improving crop water productivity in relatively wet rainfed environments (PN1 1, PN15)					
PN11: Rice landscape management for raising water productivity , conserving resources and improving livelihoods in upper catchments of Mekong and Red River basins	60%	40%			
PN15: Quesungual slash-and-mulch agro-forestry system (QSMAS): Improving crop water productivity , food security, and resource quality in the sub-humid tropics	60%	20%		10%	10%

Improving crop water productivity in irrigated and salt-affected areas (PN7, PN10, PN16)					
PN7: Development of technologies to harness the productivity potential of salt-affected areas of the Indo-Gangetic, Mekong and Karkheh river basins	100%				
PN10: Managing water and land resources for sustainable livelihoods at the interface between fresh and saline water environments in Vietnam and Bangladesh	50%		50 %		
PN16: Developing a system of temperate and tropical aerobic rice (STAR) in Asia	100%				

Questions and answers

Earlier in this section, four research areas were described, with two key questions provided for each one. To what extent do Theme 1 projects address these questions? Each question is listed and discussed in turn.

To which traits should priority be given in using molecular techniques to increase the efficiency of conventional plant breeding to improve water productivity? Molecular techniques are being used in the development of salt-tolerant varieties (project 7) and aerobic rice (project16). In addition, there was mention in project 6 of marker-assisted backcrossing in the development of drought tolerant sorghum. Priority traits depend on the crop and the context.

How can water productivity be maintained for crops growing under extended periods of mild water deficit or brief periods of severe water deficit? A number of projects seek to develop technologies to help crops get through water deficit periods. These technologies embrace a wide array of crop or system management practices (e.g., water harvesting, conservation agriculture) as well as plant breeding for drought-tolerance.

How can advances in information technologies help develop better frameworks to analyze and predict crop water productivity in different environments? Several projects use base-line surveys and agroecological zone characterization, typically linked to a GIS. To a lesser extent there is some use of simulation models, usually to examine the downside risk of introducing new technologies. There are few instances, however, where information tools are used for the specific purpose of predicting crop water productivity in different environments. The CPWF Basin Focal Projects will deal more directly with this question.

Which cropping patterns and management practices enhance production and farmers' income without increasing water input? A wide array of practices are being tested for these purposes, including water harvesting, fertilizer micro-dosing, conservation agriculture, supplementary irrigation, crop diversification, and reservoir construction. However, different sets of interventions were chosen by different projects, even in seemingly similar environments. It may be useful to explore the reasons underpinning this diversity in the selection of interventions and to identify opportunities for mutual learning.

How can the management of irrigation systems be improved to match water supplies to field water requirements, and to make more effective use of unevenly distributed rainfall and water storages? Theme 1 projects largely concentrate on improving rainfall water productivity. There is little emphasis on improving water productivity through irrigation system management.

Which sustainable strategies can improve production and water productivity in land that is degraded due to water logging and salinization? Apart from work in project 7 on salt-tolerant varieties, and work on water management in the Karkheh basin (project 8), existing Theme 1 projects do not address this question.

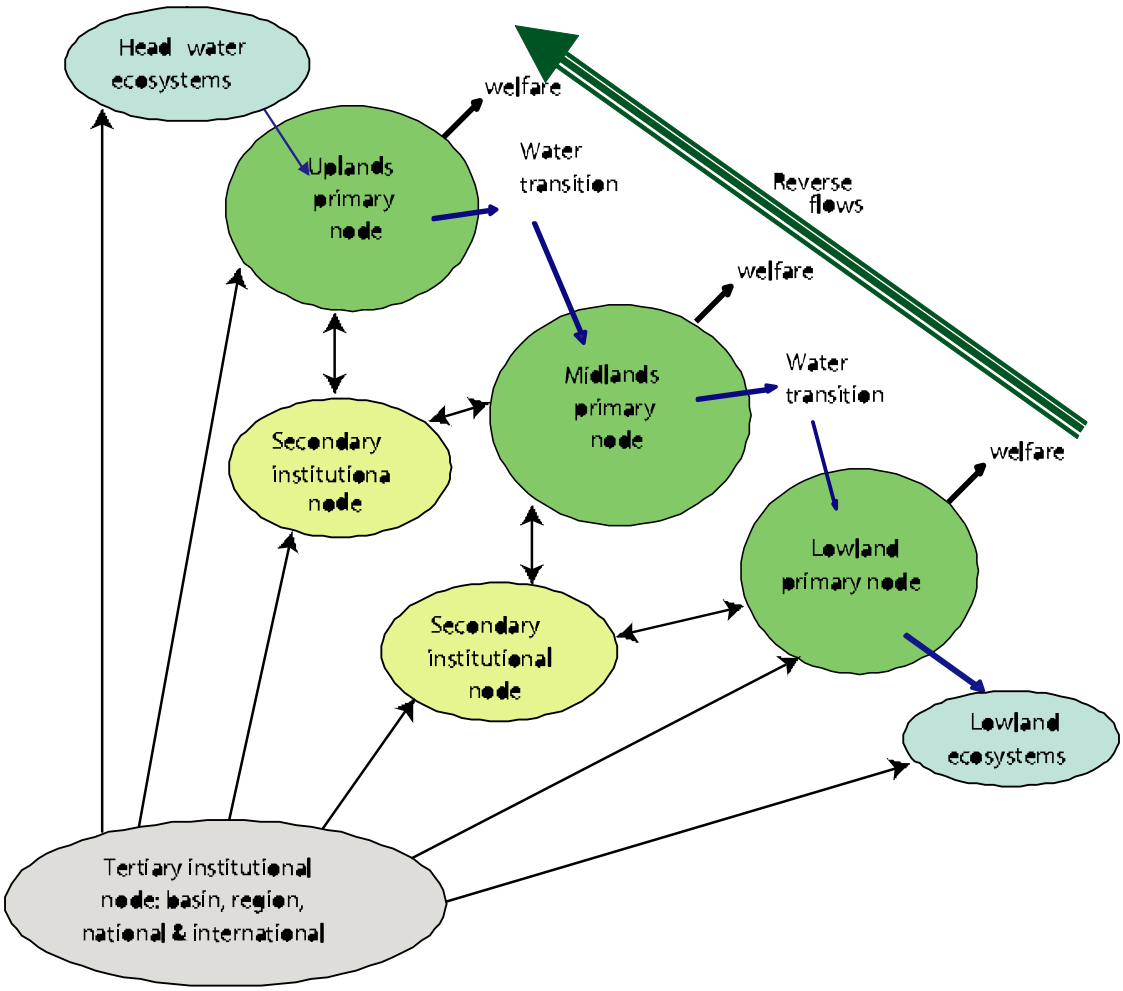
What types of policies and institutional arrangements will promote farmer adoption of water productivity-enhancing technologies? Theme 1 projects are assessing many kinds of policies and institutional arrangements for this purpose. These include community-based seed initiatives, development of market linkages, inventory credit systems, collective action in landscape management (including the prohibition of burning of fields) and policy initiatives on rainwater harvesting and farm implement development. It would be useful to identify more systematically the situations in which different kinds of policy or institutional interventions are most suitable.

How can lessons from experiences in participatory research and extension in other areas be applied? Cross-sharing of experiences in participatory techniques was rarely discussed in Theme 1 project reports. There are likely to be many untapped opportunities for cross-project exchanges on this and other topics.

Theme 2 – Water and people in catchments

Consider water flowing through a river basin. Its journey commences with rainfall or snow accumulation in a catchment. As this water flows downstream, it may be used for a succession of beneficial purposes – the production of plants, animals and fish; rural and urban direct consumption; industrial use and power generation; and the preservation of wildlife habitat and ecological processes. Figure 3 portrays this conceptual framework.

Figure 3: Conceptual model of multi-scale interactions in watershed units[6]



[6]Source: CPWF. 2006. Theme 2: Crop Water Productivity Improvement 2005 Synthesis Report

The fact that water flows downstream has an important corollary: upstream water management affects the welfare of downstream populations. People living all the way upstream, in the catchments, have first access to water resources and their water management practices impinge on all downstream users. For example, land and water management in catchments contributes to the siltation of downstream irrigation infrastructure, while water use by upstream urban centers usually reduces the quality of water available to downstream consumers.

In contrast, people living all the way downstream, e.g., in coastal areas, often must get by with whatever water resources come their way after these have been exploited, depleted, or polluted by the combined set of upstream users. Downstream people, however, are not necessarily powerless. The concept of "reverse flows" recognizes their potential ability to influence water availability through certain actions, e.g., direct payment to upstream users or lobbying of government institutions. The form that the reverse flows take is shaped by existing institutions, and on the relative wealth and power of people in the upper, middle and lower reaches of the basin. In the absence of reverse flows, downstream communities bear the consequences of water use practices used elsewhere in the basin.

In principle, coordinated use of water resources within a basin can make everyone better off. Upstream communities can be provided with incentives to avoid management practices that reduce the quantity and quality of water available for downstream users. Examples of such practices include wasteful water use in upstream agriculture, excessive use of pesticides in crop production, agricultural practices resulting in excessive erosion, and deforestation.

In reality, coordination is hard to achieve. Information on hydrological interdependence is usually lacking, as are institutional arrangements to provide individual and collective incentives for suitable water management. There may be problems of social inequalities and the exclusion and voicelessness of some groups, especially the poor and more vulnerable. A common outcome is inequitable distribution and inefficient use of water resources, degradation of catchments, loss of livelihood support and, at times, conflict.

Because water management in upper catchments affects everyone else in the basin, policymakers tend to emphasize conservation goals for these areas. But catchments may also be home to large numbers of poor people. In some parts of the world, upper catchment communities are often economically, politically and culturally marginalized, and their limited livelihood options center on the exploitation of land, water and forest resources. Equity considerations suggest that resource management in upper catchments should allow for continued productive use of water and other resources by local communities, while also conserving these resources for downstream populations. These two competing objectives must somehow be reconciled. New technologies, new land use options, and innovative institutional arrangements are needed to achieve this. Developing, adapting and scaling up these innovations form the core of Theme 2's research agenda.

Water productivity and livelihoods

CPWF projects under Theme 2 share one overarching goal, "To improve sustainable livelihoods for people who live both in upper catchments and downstream, through improvements in water management at multiple scales." Livelihoods are to be improved for everyone, regardless of where in the basin they may happen to live.

Improved water productivity in catchments plays a central role. This is because improved water productivity can result in more water available to downstream populations without reducing water use in the catchments, or otherwise harming the interests of people living there. There are at least three ways to improve water productivity in catchments.

- **Introduce new water-efficient agricultural technologies** suitable for use in catchments. These can increase downstream water availability whether or not water resources are reallocated among users.

  Design water systems that support multiple use strategies. Water management in catchments may be improved by means of an increase in the number of productive activities for which a given volume of water is used before being depleted.

  Reallocate water resources among users in ways that increase over-all water productivity in the catchment (or even within the basin) in ways that do not penalize the poor.

This last point recognizes that there may be opportunities to compensate people living in catchments for a voluntary reduction in water use, allowing it to be reallocated to activities with higher water productivity or higher impact on poverty. Consensual reallocation of water resources amongst stakeholders may be achieved by means of dialogue, informed by decision support tools, in turn based on scenario analysis made possible by suitable models. It is important that existing uses are well understood so that no one is inadvertently made worse off simply because their water rights were overlooked.

Farm families living in upper catchments may be induced to take up technologies that result in an increased downstream flow of clean water, or to voluntarily accept reallocation of water resources, through the use of suitable incentives (e.g., payments for environmental services) or institutional innovations (e.g., arrangements for collective action).

Research areas, key questions, issues, and projects

CPWF activity within Theme 2 is implemented through specific **projects** associated with **research areas** that were identified during the research planning process. Projects are intended to help answer a number of pre-determined **key questions**. In this synthesis, Theme 2 projects are further grouped around specific issues that reflect opportunities for improved water management in catchments. Projects tend to touch on several research areas and address more than one key question, but usually focus on a single issue. At present, most Theme 2 research is concentrated in the Andes, Mekong, Limpopo and Nile basins, although some research is conducted in all basins.

Three **research areas** were identified by Theme 2 participants and stakeholders. These are listed below. They can be more generally interpreted in terms of "problem diagnosis", "the development of solutions", and "fostering the widespread use of suitable solutions". Many projects use a problem-solving approach that incorporates all three research areas.

1. Better understanding of water and poverty in catchments. Two key questions were identified:

- What is the significance of water to the livelihoods of inhabitants of upper catchments, especially the poor and how is this reflected in their role as managers of watershed resources?
- What are measurable and predictable impacts of changes in water management on poverty alleviation?

2. Identifying the potential for improving land and water management in catchments. Key questions are:

- What are the opportunities for improved water productivity within upper catchments and what risks are associated with specific land management changes?
- What are key indicators of risks? What risk management strategies are available/ appropriate? Where can technological and management advances provide win-win situations? Are trade offs between uses and users significant, if so how can decision makers assess them?
- How can the outcome of specified changes be assessed for large areas for which data is sparse? How can participatory action research and inclusion of local knowledge contribute to this assessment?

3. Enabling change. Key questions include:

- How can the system accelerate overall improvement in water productivity without exacerbating inequalities in power?
- What are the characteristics of effective institutions for managing water resources?

The three research areas tend to be utilized simultaneously in addressing the following **issues**:

1. *Using technical change in catchments to improve downstream water availability (projects 11, 17, 24)*
2. *Designing water systems to support multiple uses (PN 28)*
3. *Reallocating water resources among users for improved productivity and equity (projects 25, 30, 40)*
4. *Fostering the adoption of water-efficient practices in catchments (projects 20, 22)*

Using technical change in catchments to improve downstream water availability[1]

There are a number of ways to improve water management – and ultimately water productivity and livelihoods – in upper catchments. One of the most important is through the introduction of "water-efficient" technologies for crop and livestock production and landscape management. These technologies can increase the amount of good quality water available for downstream use while simultaneously expanding food production in catchments. Water-efficient technologies have relevance for virtually all catchments, whether these have a wet or dry climate, or a sloping or relatively flat topography.

The process whereby these technologies are developed and adapted is similar across projects. The process includes diagnosis (including activities to better understand the link between poverty and water – research area one); **technology development** (based on an understanding of the potential for improving land and water management in catchments – research area two); and **fostering technology** use (in part by enabling change – research area three).

Many CPWF projects deal with questions of crop water productivity and technical change, but only three of them seek to assess off-site and downstream effects of new technologies introduced into upper catchments. One such project is located in a relatively humid environment (Mekong basin – project 11). The other two are located in dry environments (Karkheh and Limpopo basins – project 24 and project 17).

In the **Karkheh** basin, project 24 is seeking technologies to **reduce soil erosion** harmful to downstream irrigation infrastructure while **improving livelihoods in upper catchments**. Widespread use of suitable technologies is to be fostered by policy support combined with a strengthening of local capacity.

During 2005, site selection and diagnosis were emphasized. Out of sixteen possible locations, two typical but diverse catchments (Merak in Kermanshah Province and Honam in Lorestan Province) were selected for project activities. It is felt that in these locations, the project can achieve its objectives while also serving as a basis for scaling out. Diagnostic activities featured the development of a framework for evaluating livelihood vulnerability and resilience in dry areas. Field surveys were conducted on needs assessment, farmers' innovations, catchment hydrology, vegetation cover, nutrient flows, soil types, and soil erosion. The assessment of soil erosion uses simple methods based on local knowledge. Locations where data was collected were geo-referenced using GPS receivers. Diagnostic analysis will thus include an explicit spatial dimension.

In the **Limpopo basin**, project 17 is working on ways to improve food security and livelihoods in a risky, drought-prone environment – in ways that do not have undesirable off-site consequences. Diagnostic work has included a survey on water productivity, yield gaps, and the use of **rainwater harvesting systems** (WHS) in four districts in the Mzingwane Catchment. Survey results are being used to understand farmers' WHS, find opportunities to improve them, and identify alternative, prototype water management technologies.

The challenge is to foster a process of participatory technology adaptation, supported by local institutions and policies, and based on an IWRM framework. Farmers and other stakeholders can

form a dynamic innovation system for tailoring prototype technologies to local environmental and socio-economic circumstances. They can also help assess the extent to which adapted technologies reduce risk, improve yields, or in other ways contribute to improved livelihoods. Project partners can facilitate this process, while concurrently monitoring the impact of technical change on water productivity in catchments, and water availability elsewhere in the basin.

Finally, in the **Mekong** basin, Project 11 (also discussed in the context of Theme 1) seeks to design **land-use options** that improve water productivity at different scales (household to catchment), improve access to water by the poor, and assure sustainable food security to farmers living in upper catchments. In partnership with stakeholders, the project aims to:

- Develop, test and validate new technologies for producing rice and other food items.
- Develop, test and validate innovative approaches at the landscape level for managing water and land in ways that contribute to sustainable food security and environmental protection.

Combining these two, the project more specifically seeks to design a mosaic of improved land-use and agricultural practices that take into account resource allocations and flows—of water, nutrients, labor, and capital—and their interactions across the landscape. In doing so, the project will develop an integrated strategy for improving food security through intensification of rice production in paddies in the upper catchments while providing options for the sustainable use of soil and water resources in the sloping parts of the catchments for income generation. At the moment, however, this project is in its early days.

Designing water systems to support multiple uses

Virtually all people use water for a multiplicity of domestic and productive purposes. Poor people living in upper catchments are particularly likely to rely on a wide range of water-dependent activities for their livelihoods. This "multiple uses of water" strategy increases their welfare – and also tends to increase water productivity (research area one).

Unfortunately, most water supply systems have been designed with a single use in mind, e.g., irrigation or direct consumption. Not infrequently, they are simply unable to cope with the demands (volume of water required or the timing of water delivery) that may be placed on them by the "multiple uses of water" strategies often preferred by poor households. The answer may lie with water supply systems that are multiple-use by design.

One CPWF project working in the **Andes**, **Indus-Ganges**, **Limpopo**, and **Mekong** basins (Project 28) focuses specifically on this issue. Evidence gathered to date suggests that water supply systems that are multiple-use are more responsive to poor people's needs and have a greater impact on reducing poverty. Multiple-use systems (MUS) by design are also expected to be more sustainable because system overload is less likely to occur, and because people are more willing to pay for their upkeep since they obtain more benefits.

When rural water supply systems are designed and built with a multiple-use perspective, many costly technical difficulties can be avoided. And in practice, it appears that the greatest barriers to MUS are not technological but rather institutional. Sectoral interests in single use systems are entrenched at community, regional and national levels. Still, participants in PN28 have discovered that convincing people of the advantages of MUS is not difficult. The question is less "why MUS?" than "how MUS?" The project aims to answer this question through an action research approach called a **Learning Alliance** (LA).

A LA is an exercise in participatory monitoring and evaluation, employed for "enabling change" (research area three). It involves individuals and institutions (working at the community, intermediate, and national levels) in pilot sites were MUS approaches are being designed and implemented. The purpose of the LA is to identify the challenges associated with the implementation of MUS, to

look for innovative solutions, and, in the process, to test a set of general design principles for MUS. Project researchers support LA partners and synthesize results across sites. Because LAs work across scales within sites, mechanisms for scaling up are built into the process.

LAs are currently in place in Andes, Indus-Ganges, Limpopo and Mekong basins. In the Andes, MUS case studies have been initiated in Colombia and Bolivia. In Colombia, studies include national policy and legal dimensions – and how new national water legislation can enable MUS approaches. In the Indus-Ganges, three MUS test sites have been launched. Key national partners have been contacted regarding the possible implementation of combined domestic water supply and drip-kit irrigation systems. In the Limpopo, Learning Alliances are being formed in South Africa and Zimbabwe. And in the Nile, action research on MUS has begun in four small watersheds in north and east Ethiopia.

The success of the MUS in multiple basins suggests that the time is ripe for the forging of global Learning Alliances and the swift scaling out of MUS approaches.

Reallocating water resources among users for improved productivity and equity

Because of interdependence among water users, success in improving catchment management (and thereby water productivity) usually requires coordinated action. Such coordination is most readily achieved when incentives, norms and regulations (set and enforced by formal or informal institutions) result in individuals and communities voluntarily changing their water management practices. One outcome is that some stakeholders may receive more water, and others less, than otherwise would be the case.

For this to happen consensually, it must be founded on agreements amongst stakeholders – agreements that are best forged through informed debate, and shaped so that everyone benefits. The efficiency of this debate, and the suitability of proposed agreements, can be enhanced through a combination of stakeholder analysis, modeling, scenario analysis, and the application by stakeholders of decision-support systems. Capacity building, especially in model development and use in decision-support systems, is critically important.

Stakeholder analysis - Different stakeholders with differing perceptions of water dynamics adopt various strategies to cope with water-related problems. Stakeholder analysis helps achieve an understanding of the factors influencing stakeholder perceptions and how they might be modified to allow greater coordination and equity in water use. Stakeholder analysis is complemented with other diagnostic activities that help improve understanding of poverty and water in catchments (research area 1).

Modeling, scenario analysis and decision-support tools – Models can help examine the likely outcomes of policy and technology options on water allocation and water productivity – and how these outcomes may affect different stakeholder groups (research area two). The information thus generated can serve to stimulate stakeholder dialogue on water dynamics, resource sharing and water-related conflicts. When incorporated into decision support tools, this information allows stakeholders to visualize the outcomes of different scenarios.

There are several CPWF projects that aim to improve water allocation in catchments by fostering informed stakeholder dialogue. These projects are being implemented in the Andean, Limpopo, Mekong, and Volta basins. The underlying assumption for these projects is that catchments can be managed in a sustainable way, that a balance between protection and production can be achieved, and that improvements in water productivity may be brought about by changes in the allocation of water resources.

In the **Andean** and **Volta** basins, CPWF project PN40 aims to strengthen **multi-stakeholder governance structures** in two project sites, one in Ghana and one in Chile. Governance structures are

thought to be important because they are the venue where negotiations occur at the sub-basin level on questions of water allocation. These structures are to be strengthened by identifying problems, shaping policy options, and establishing criteria for their evaluation by stakeholders. Project 40 is discussed in more detail in the context of Theme 4.

Stakeholder evaluation of policy options is to be assisted by a simulation model capable of "predicting agent-agent and agent-environment interactions". The simulation model in question integrates a climate model, a hydrological model and an agent-based socio-economic model. Decision support tools are to be designed that will allow stakeholders to better visualize the outcomes of different simulation scenarios. The intent is to use these decision support tools during actual processes of negotiation and planning within the governance structures in question.

In the **Mekong** basin, another project (project 25) intends to employ a further development of agent-based building called "**companion modeling**". This is defined as the combined use of agent-based models and participatory role-playing games (drawn from experimental economics) for collective learning and resource management. It is described as a way of linking the biophysical and socioeconomic characteristics of a system. This approach is said to feature "participatory methods to elicit stakeholders' knowledge and perceptions of water dynamics, examine scenarios of resource sharing, and stimulate dialogue" in order to help resolve water-related conflicts among stakeholders.

This project was only approved near the end of 2005, so progress during that year was necessarily limited. Nonetheless, during the project inception workshop, plans were made to make use of past work on model development for application in watersheds located in Chiang Mai, Chiang Rai, and Lam Dome Yai (Thailand); Bac Lieu (Vietnam); and Lingmuteychu (Bhutan).

A third CPWF project, focusing on wetland management in the **Limpopo** basin (project 30), employs a similar approach. This project uses models as a "framework for analyzing trade-offs between food production/security and environmental security" – specifically the trade-offs among alternative mixtures of agricultural (crop and livestock) and fisheries water-use strategies in *dambos* and riverine swamps. Models are used to assess different scenarios through a "comparative analysis of social welfare benefits accruing from various options for wetland water use for agriculture, and the trade-offs among them . . ." The intent is to draw on model outcomes to develop **guidelines for wetland utilization**. These guidelines may then be utilized by extension workers; traditional decision makers, and wetland users; and may further serve as a foundation for the development of policies to govern wetland use.

During 2005, two project locations were chosen (Chibuto and Intunjambili), a baseline survey was conducted, detailed land use maps were produced, a trade-offs conceptual framework paper and an initial model were developed for the Chibuto site, and interactive meetings with farmers were held. These focused on the multiple uses of wetlands and the inherent conflicts between livestock and crop producers in accessing them. Project 30 is discussed in more detail in the section on Theme 3.

In all cases, these CPWF projects aim to **strengthen the capacity of local institutions** to conduct stakeholder analysis and model the outcomes of different scenarios to inform the decision-making process (research area three). Good, well-informed decision-making on water allocation can be a powerful means of improving water productivity and livelihoods.

Fostering the adoption of water-efficient practices in catchments

Numerous interventions have been described above for improving water management and enhancing water productivity and livelihoods in upper catchments. These interventions include "water-efficient" technologies for crop and livestock production and landscape management; the introduction of water systems designed for multiple

uses; and the voluntary reallocation of water among users from lower to higher productivity uses in ways that enhance rather than harm the livelihoods of the poor.

Two CPWF projects have the specific aim of accelerating the widespread adoption of such interventions through the provision of suitable incentives. One of these projects (project 22) explores the notion of compensating poor people in catchments for their contribution in providing environmental services. The other project, (project 20) looks at a particular institutional innovation – collective action.

Water productivity is a measure of output per unit of water depleted, with water pollution being one form of depletion. The main hypothesis of project 22 is that water pollution and soil erosion in catchments ("environmental externalities") can be reduced, thereby improving water productivity, and that this can be done in ways that simultaneously contribute directly to poverty reduction. The project explores one unique way of achieving this – increasing the flow of financial resources from governments and civil society to poor producers living in catchments. The "flow of resources" examined in the project include credit arrangements and **payments for environmental services** (PES).

Project researchers are testing this hypothesis with a model that assesses the hydrological, economic and social impacts of different land management practices within a catchment. During 2005, modeling was completed for two pilot sites in the **Andes**: Fuquene (Colombia) and Altomayo (Perú). Soil and greenhouse gas samples were collected to measure the impact of land use practices on soil properties, C sequestration and hydrological externalities. In one study, natural stable isotopes were used to identify non-point sources of nitrates and phosphates, thereby establishing a causal relationship between land use and water pollution. On the basis of these results, (1) an optimization model for externalities valuation and opportunity cost calculation was developed; (2) hydrological response units were identified and prioritized according with their contribution to environmental externalities (water flow, sedimentation) and (3) the model was used for ex ante evaluation of land use scenarios.

In Fuquene, results indicated that conservation agriculture practices (green manures, reduced tillage and direct drilling) had positive impacts employment generation and on farmer's income – and also on soil retention and erosion control. As a consequence, these practices were selected for promotion through a strategic alliance with banks and the national financial system. Farmers who adopt conservation agriculture practices are eligible to receive loans and guarantees. Special provisions have been made to include small farmers.

In Altomayo watershed (Peru), preliminary results from a similar kind of analysis have been shared with local partners. They have now decided to promote directly the development of a mechanism of payment for environmental services for conserving the upper catchments that supply water to urban areas.

To date, the main achievements of project 22 have been in Andes basin. The intention is to begin similar activities in the **Nile** basin as well.

Because of the interdependencies among water users in a basin, coordinated water use can make everyone better off. Sometimes, this coordination is most effective when it takes the form of **collective action** in resource management in catchments. With regard to this, project 20 has begun to examine the relationships among collective action, poverty and scale.

As it happens, the dynamic biophysical, social and political interactions that take place across different watershed scales typically are not well understood. This project proposes to seek a deeper understanding of these interactions – and then to use this understanding to show how collective action by people living in catchments can help them escape from poverty.

Even when collective action in a catchment is important, it may be difficult to attain the participation of all stakeholders. Some may not be willing or able to participate. Poverty and power are often factors that determine participation – the rich

or powerful may opt out while the poor or powerless are excluded. This project looks at some of the diverse sources of both poverty and power in watershed context, and their implications for watershed research and development.

Preliminary project results from the **Andes** show that there are often both direct and indirect relationships between water and welfare within catchments, and that there may be tradeoffs between environmental benefits and poverty reduction. Some large polluters are important sources of employment for the poor. National partners in Kenya are using the participatory poverty method for their own diagnostic and priority setting activities. Future work will explore how strategies featuring collective action can improve water productivity and livelihoods in catchments, and what factors support or constrain the emergence of collective solutions.

Issues and basins

A look at the distribution of Theme 2 issues across basins reveals some interesting patterns. These are shown in Table 5.

There is considerable overlap across the Andes, Limpopo, Mekong and Volta basins in methods used to address the issue of "Reallocating water resources among users for improved productivity and equity". There may be opportunities here for cross-project and cross-basin sharing and learning.

Apart from some work on conservation agriculture in project 22, there is virtually no Theme 2 activity in the Andes basin on the issue of "Using technical change in catchments to improve downstream water availability", even if the focus is on off-site consequences. This is also true for Theme 1. A question might be raised as to why technical change for improved farm-level water productivity has apparently been neglected in that basin.[8]

There is no apparent link within basins on activities to reallocate water, and activities focusing on technical change to improve farm-level water productivity, after this re-allocation has taken place.[9] There may be opportunities here for improved basin-level integration of activity.

Projects and themes

Most CPWF projects address more than one of the five CPWF Themes. Although the projects described in this section have large assignments to Theme 2, none of them are assigned exclusively to this Theme.

More specifically, those projects that address the issue of "Increasing farm-level water productivity in catchments through technical change" are also assigned to Theme 1. This is a clear area of overlap between Themes 1 and 2. Similarly, projects addressing the issue of "Reallocating water resources in catchments towards high productivity uses" are also assigned to Theme 4. However, only a few Theme 2 projects share assignments to Themes 3 or 5 to any substantial degree.

Table 6 displays the distribution of Theme 2 projects across all five Themes.

There are a number of projects assigned both to Themes 1 and 2. The interest of Theme 2 in these projects is principally in the assessment of off-site catchment-level consequences of new technologies, rather than the process of generating new technologies as such

[8]Similarly, there is no Theme 2 research on technical change for farm-level water productivity in the Volta and other basins. However, in these cases, there is adequate attention paid to the issue in Theme 1.

[9]The direction of causality can also go the other way – when new technologies make water reallocation possible, a link between the two is important. In either case, it appears that this link can be strengthened. This can be done by the Basin Focal Projects.

Table 5 : Project focus by basin and issue, Theme 2

	Andes			Karkheh	Limpopo		Mekong		Volta	Cross-basin
	20	22	40	24	17	30	11	25	40	28
Using technical change in catchments to improve downstream water availability (PN 11, 17, 24)				Technical charge in dry rainfed environments	Technical charge in dry rainfed environments		Technical charge in dry rainfed environments			
Designing Water systems to support multiple uses (PN 28)										Multiple use systems, Learning Alliances (Andes, Indus-Ganges, Limpopo Mekong
Reallocating water resources among users for improved productivity and equity (PN 25, 30, 40)			Agent-based modeling to improve multi stakeholder governance structures			Decision support for use of wetlands in dry environments		Companion modeling and decision support to stimulate dialogue on water allocation and water related Conflicts	Agent based modeling to improve multi-stakeholder governance structures	
Fostering the adoption of water efficient practices in catchments (PN 20, 22)	Collective action	Payments for *environment* all services								

Table 6 : Distribution across Themes of projects with a large assignment to Theme 2

Domains and project	*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 – The Global food and water system*
Using technical change in catchments to improve downstream water availability (PN 1 1, 17, 24)					
PN11: Rice Landscape Management for Raising Water Productivity, Conserving Resources and Improving Livelihoods in Upper Catchments of the Mekong and Red River Basins	60%	40%			
PN17: 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%	
PN24: Strengthening livelihood resilience in upper catchments of dry areas by integrated natural-resources management	20%	65%		5%	10%
Designing water systems to support multiple uses (PN 28)					
PN28: Models for implementing multiple-use water supply systems for enhanced land and water productivity, rural livelihoods and gender equity	20%	50%	10%	10%	10%
Reallocating water resources among users for improved productivity and equity (PN 25, 30, 40)					
PN25: Companion modeling for resilient water management: Stakeholders' perceptions of water dynamics and collective learning at the catchment scale		80%		20%	
PN30: Wetlands-based livelihoods in the Limpopo basin: Balancing social welfare and environmental security	10%	30%	30%	30%	
PN40: Integrating knowledge from computational modeling with multi-stakeholder governance: Towards more secure livelihoods through improved tools for integrated river basin management		40%		50%	10%
Fostering the adoption of water-efficient practices in catchments (PN 20, 22)					
PN20: Sustaining inclusive collective action that links across economic and ecological scales in upper watersheds (SCALES)		50%		25%	25%
PN22: Payment for environmental services as a mechanism for promoting rural development in the upper watersheds of the tropics	5%	60%		18%	17%

Theme 3 – Aquatic ecosystems and fisheries

Previous sections have discussed crop water productivity in mainstream agricultural areas, and resource management in upper catchments. A connection between crop water productivity and food security is intuitive and readily understood. Links between land and water management in upper catchments and downstream water quality are similarly clear. There is a less obvious connection, however, between the management of aquatic ecosystems and fisheries, nutrition for the poor, and the production of environmental goods and services. Being less obvious, this connection is often overlooked.

As it happens, large numbers of the poor depend on aquatic resources for their food and livelihoods. 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 healthy children. But as demand for water increases and water development plans are launched, the interests of the poor sometimes receive a low priority from policymakers, planners and resource managers. A similarly low priority may be given to preserving the environmental and ecological functions of aquatic ecosystems.

More information might help. Policymakers and planners might be able to improve their decision-making if they had easier access to better information on such issues as: trade-offs among alternative uses of wetlands; the value of environmental services produced by aquatic ecosystems; the environmental flow requirements of rivers; how aquatic ecosystems affect water productivity; and ways in which aquatic ecosystem productivity might be improved through innovative technologies, policies, institutions and systems of governance. This is the kind of information, with complementary decision support tools, that is emerging from research conducted under the CPWF Theme 3 - Aquatic ecosystems and fisheries.

Research areas, key questions, issues and projects

As is the case with other Themes, CPWF research under Theme 3 is organized into research areas, guided by key questions, and implemented through specific projects. Projects usually touch on several research areas and address more than one key question. In contrast, they tend to focus on one particular issue. For the purposes of this synthesis, issues are defined in terms of problems encountered in upstream vs. downstream sections of a river basin.

At present, most Theme 3 research is concentrated in two basins, the Indus-Ganges and the Mekong, with some work being initiated in the three African benchmark basins. Lessons learned, however, will be shared for further application in suitable areas of other basins.

Research areas for Theme 3 include the following:

1. *Institutional mechanisms, especially for integrating fish and crop production*. Key questions[1] include:
   - What are the factors that influence people's access to, and control over, aquatic ecosystems and their resources?
2. *New technologies to further improve integration of fisheries into farming systems.* The related key questions is:
   - When and how can water productivity and livelihoods be improved by integrating fish production and the harvesting of other aquatic animals and plants into farming and irrigation/ flood-prone systems?
3. *Tools, methodologies and management approaches for governance*. Key questions are:
   - What kinds of governance systems and

[1] For Themes 1 and 2, key questions were associated with specific research areas during the research planning process. For Theme 3, questions were related to research areas during synthesis

enabling policies and institutions foster equitable and sustainable management of aquatic ecosystems?

- What are the appropriate tools for generating timely information for use by poor stakeholders?

4. Determination of the monetary and non-monetary value of goods and services provided by different types of aquatic ecosystems – strategies for improving wetlands livelihoods. Key questions include:

- What are the monetary and non-monetary values of goods and services provided by different types of aquatic ecosystems?

5. Methodologies for assessing water productivity in fisheries; strategies for managing reservoir fisheries – policies for sustainable fisheries. The key question is:

- How can capacity be built within national and local institutions to ensure that poor people's needs are taken into account in policy development and governance processes?

Issues addressed under Theme 3 (moving from upstream to downstream) are listed below. Most if not all research areas will be relevant in addressing each issue.

1. Managing wetlands in dry environments.

2. Managing fisheries in tropical reservoirs.

3. Managing fisheries in irrigated fields, floodplains and deltaic lowlands.

4. Managing the saline – freshwater interface in coastal areas.

5. Fisheries management across scales.

The relationships among research areas, benchmark basins, issues, and projects are shown in Table 7.

Apart from the several projects, Theme 3 research also includes a state-of-the-art review of good governance in fisheries. This review was commissioned during the year 2004 and has resulted in new insights. It appears that good governance in this context is characterized by decentralization, co-management, the participation of all stakeholders in the decision-making process, and an equitable distribution of benefits.

Managing wetlands in dry environments

Much of the landscape of southern Africa is covered by thin, sandy soils that only just cover an underlying layer of impermeable rock. Typically these soils are of low fertility and have low water-holding capacity. Because of this, much of the rain that falls during the wet season moves laterally, ending up in riverine swamps or localized wetlands known locally as *dambos* or *vleis*. These wetlands account for only a small proportion of the land area – but their value is high relative to that of other landtypes. These wetlands have many potential uses. They can be used for relatively intensive agriculture, watering livestock, producing fish, or generating environmental goods and services. The importance of the latter is often ignored.

Table 7 : Research areas by basins and issues, Theme 3

	Issue				
	Managing wetlands in dry environments	Managing fisheries in tropical reservoirs	Managing fisheries in irrigated fields, floodplains and deltails dowlands	Managing the saline - freshwater interface in coastal areas	Fisheries management across scales
Basin	Limpopo	Indus-Ganges, Nile, Volta	Indus-Ganges, Mekong	Indus-Ganges, Mekong	Mekong
Project No.[11]	30	34	35	10	52
Institutional mechanisms, especially for integrating fish and crop production					
New technologies to further improve integration of fisheries into farming systems					
Tools, methodologies and management approaches for governance					
Determination of the monetary and non-monetary value of goods and services provided by different types of aquatic ecosystems- Strategies for improving wetlands livelihoods					
Methodologies for assessing water productivity in fisheries; strategies for managing reservoir fisheries; Policies for sustainable fisheries					

[11] In Table 6, only one project appears per issue. This is merely a coincidence, due to the relatively small number of projects primarily located within Theme 3. As has been seen, it is more common for multiple projects to be devoted to the study of a particular issue.

It would be highly desirable if all productive uses of wetlands – agriculture, livestock, fisheries, and environmental services – could be made to increase simultaneously. Unfortunately, this is not usually the case. Increased use of wetlands for agriculture and livestock typically implies a reduction in their use for fisheries, or for the generation of environmental goods and services. Conversely, the preservation of wetlands for fisheries or environmental services may imply forgoing their use for crops and livestock.

In this context, trade-off analysis takes on a hugely important role.

Within the CPWF portfolio, one project (30) specifically focuses on analyzing trade-offs among different uses of wetlands in dry environments. Specifically, the project aims to assess trade-offs among crop, livestock and fisheries water use strategies in *dambos* and riverine swamps in upper and lower catchments in the **Limpopo** River basin. The intention is to develop a tool, rooted in trade-off analysis, which can help inform decisions on wetland use and conservation. Among other things, this tool should be capable of determining the extent to which it is possible to increase the use of wetlands to support people's livelihoods without compromising environmental security. Project 30 is also discussed in the context of Theme 2.

This project is beginning to make progress.

- A conceptual framework has been developed for assessing the consequences of different mixtures of wetland uses. This framework combines participatory methods, field observations, surveys and the use of formal models to simulate outcomes from alternative land use scenarios.
- A literature review has been compiled on the economic valuation of wetlands goods and services. This has been published in the form of a conference paper.
- Two suitable sites for the project have been identified, one in upper Limpopo (Matopos, Tuli River catchment, Zimbabwe), and the second one in the Lower Limpopo (Chibuto, Changane catchment, Mozambique). Stakeholder analysis is proceeding in both sites.
- The physical delineation of sites has been completed. Protocols have been developed for using Landsat imagery for GIS mapping of wetland areas, and ground truthing is in progress. Landsat images are available for multiple years, making possible an assessment of changes in wetland use over time. In one early finding, GIS analysis indicated that the wetland area in Mafefe, South Africa, has since the late 1970s lost a large proportion of its surface area to agriculture.
- In another early finding, competition among stakeholders for different *agricultural* uses for wetlands was found to be important. An instance was found where some community members had installed an irrigation system to expand vegetable production. However, this led to the drainage of a separate portion of the agroecosystem where other members of the community have been accustomed to growing bananas and rice.

Lessons learned from research on this issue may be relevant to similar areas in other benchmark basins where there is competition among multiple uses (including environmental uses) for access to valuable, scarce wetlands.

Managing fisheries in tropical reservoirs

The wetlands described above are naturally-occurring "sinks" where scarce rainwater tends to concentrate because of lateral flows. In contrast, the tropical reservoirs discussed in this section are naturally-occurring or artificially-created bodies of water, fed by rivers or streams, whose primary use is to produce fish.

A sustainable increase in fish production from these tropical reservoirs would be highly desirable, especially if this contributes to improved food security for the poor and to improvements in water productivity. Fortunately, it appears that there are substantial opportunities for increasing fish harvests in these reservoirs through a combination of better harvesting strategies, stock enhancement, and related aquaculture activities.

One CPWF project (34) is examining this issue in four selected reservoirs in the **Ganges, Nile** and

Volta benchmark basins, with built-in comparisons with other basins. Activities include characterizing a wide variety of tropical reservoirs, assessing and diagnosing issues related to fisheries in the selected reservoirs, working with local fishing communities to develop tools and strategies for enhancing fish harvests, designing co-management arrangements, evaluating markets, disseminating results, and engaging in training and capacity building. Complementary research is to be done on assessing water quality in reservoirs as affected by fisheries management strategies.

Work on this issue is just now beginning. Inception workshops have been held for the Volta and Ganges sites but, in most cases, field research as such has not yet commenced.

Managing fisheries in irrigated fields, floodplains and deltaic lowlands

In several benchmark basins, substantial areas of agricultural land in floodplains and deltaic lowlands are subjected on a regular basis to seasonal flooding. Such flooding may last for several months. Curiously, some of these lands may be used during the dry season for irrigated agriculture. During the time in which they are affected by flooding, however, they normally cannot be used for crop production. (One exception is the localized production, under some circumstances, of deepwater rice.)

In the eastern Ganges, for example, there is a vast area that is seasonally flooded or flood-prone, or seasonally or permanently affected by waterlogging or poor drainage. These areas are found in the Nepal Terai, Bihar, West Bengal and Bangladesh. They are characterized by low land and water productivity and a relatively high incidence of poverty.

Although floodwaters may perform ecological and environmental functions (e.g., flushing of silt, revitalization of wetlands), they typically are not used in ways that contribute directly to the livelihoods of the poor. In this sense, water productivity is low. There is reason to believe, however, that untapped opportunities exist for using these waters to support managed aquatic production systems. This might be accomplished by enclosing parts of flooded areas to produce a "crop" of specifically stocked aquatic organisms. Strategies that feature enclosures, however, may run up against issues of property rights. There is an underlying assumption that seasonal water bodies created by flooding can be communally managed by stakeholders under equitable and sustainable sharing arrangements. Recent work in Vietnam and Bangladesh suggests that such an approach may be feasible.

One CPWF project (35) is exploring this possibility through activities in two benchmark basins – the Indus-Ganges and the Mekong. (There may be opportunities in the future to expand activities to the Volta and Yellow River basins.) A key output of the project will be technical options for integrating fish and other living aquatic resources into irrigation systems and seasonal floodplains, in the context of locally rooted institutions. Success in this work might help mitigate the observed declining trend in inland capture fisheries production.

CPWF work on this issue will contribute to the development of governance systems, policies and institutional arrangements to foster equitable and sustainable management of seasonal aquatic ecosystems. It will also generate the appropriate technical and institutional options for increasing water productivity at basin level through integration of community-based fish production with other agricultural production systems.

As with some other issues, work on this issue is just now beginning. Inception workshops have been held but, in most cases, field research as such has not yet commenced.

Managing the saline - freshwater interface in coastal areas

There are times when saltwater from the sea moves up into the river, at times for a considerable distance. This occurs, for example, in the Mekong and the Ganges. Saltwater intrusion is most likely

to occur during the dry season, when river hydraulic pressure is low. Such intrusion can pose problems for some people (e.g., rice farmers whose dry season rice crops may be harmed) while presenting opportunities for others (e.g., shrimp farmers who can temporarily expand the scale of their operations).

There are at least three ways out of this dilemma. CPWF project 10 is examining three ways to deal with such situations.

One way is to develop technologies that reduce or eliminate the harm done to crops by saltwater intrusion. Discussion under Theme 1, for example, described project 10 work in Batiaghata, Bangladesh, where a short duration *Aus* (dry season) rice crop was successfully introduced by using for irrigation the rain water that has been harvested and then stored in farm canal networks – even while the surrounding river water has temporarily become saline due to sea water incursion.

Another way is to develop technologies that transform saltwater intrusion from a problem into an opportunity. In the lower Mekong Delta, for example, rice farmers are learning to take up shrimp culture when water quality conditions so dictate. Similarly, in the lower Ganges, research is being conducted in rice-fish and shrimp poly-culture. The latter utilizes rainfall for rice in the rainy season, then brackish water for shrimp in the dry season.

Sometimes, however, "win-win" outcomes are not possible. A third way, then, is to develop or improve institutions to manage the conflicting interests of different water users. This can be difficult to achieve. There is often a huge diversity of rural livelihood strategies in coastal zones, making it hard to anticipate the consequences of different water management interventions (e.g., changes in water allocations, or the introduction of new technologies) on different stakeholder groups. It is even more difficult to anticipate the environmental consequences for water quality and aquatic biodiversity of these interventions.

Project 10 is specifically focused on this issue. This project aims to increase land and water productivity in the Mekong Delta for improved food security and livelihoods, in a manner that is environmentally sustainable and socially acceptable to various resource users. It will do so by carrying out INRM research that takes account of diverse stakeholder interests and complex multi-scale upstream-downstream interactions.

This typically requires the use of effective decision support systems. CPWF projects are making progress in designing or improving models that underpin such systems. For example, the "BayFish" model has been refined to take more explicit account of coastal zone parameters, thus enabling it to more effectively anticipate the differential effect of alternative sluice gate operations. This model integrates the saline/freshwater requirements of each production component (rice, shrimp, fish, crab), and the trade offs between them.

Progress is also being made in the lower Ganges (Bangladesh) where project 10 is developing policy guidelines and institutional arrangements for improving the land and water productivity of for rice-rice and rice shrimp systems in coastal ecosystems. So far, a benchmark survey has been successfully completed. This will serve as a basis for further progress in 2006.

Agricultural technologies developed through such research will increase rice yields and cropping intensity, therefore improving food security. Similarly, aquacultural technologies will increase aquaculture production and stability. Poor farmers and fishers who rely on capture fishery and wild aquatic products, will benefit from better institutional and regulatory frameworks for resource management to sustain aquatic biodiversity and fisheries. These are especially important for poor women and children who are most dependent on capture fishery for their protein intake.

Fisheries management across scales

This issue is different from other Theme 3 issues. Research on the other issues has used a fairly localized focus on one component of a landscape. Research on this issue, however, moves up to a larger scale, seeking insights into fisheries management systems (by means of a synthesis of an array of localized experiences) at the level of the Mekong basin. Scaling-up draws on local-level natural resource management institutions, through national fisheries management and research agencies, to the basin-level via the Mekong River Commission.

Work on this issue is largely implemented through CPWF project 52. The project in question anticipates a series of useful outputs, including guidance on governance systems for fisheries; policies and institutions for cross-scale management for use by community-based fisheries management institutions and local/national government institutions in the Lower Mekong countries. In addition, it aims to strengthen the information and communication capacity of decentralized fisheries institutions. Other information outputs will include relevant experiences in the design and implementation of community-based natural resource management, and its scaling up from local to regional levels. This project also aims to support on-going research work carried out by the Mekong River Commission.

This is an ambitious, far-ranging project, whose activity, however, is just now beginning.

Development of partnerships/ communities of practice

Building partnerships and forming communities of practices (COP) is an important part of CPWF work under Theme 3. COPs are active in the Nile, Indo-Gangetic, Volta and São Francisco basins, where they have helped update basin priorities and identify areas where the CPWF can add value to on-going activities. Consultations with COPs has helped bring into focus such basin-specific priorities as trans-boundary management of aquatic ecosystems in the Indo-Gangetic; fisheries enhancement in the Volta; riverine and lake fisheries in the Nile; and the environmental flows in São Francisco basins.

Issues and basins, projects and themes

CPWF work in Theme 3 is heavily concentrated in the Indus-Ganges and Mekong basins, with some activity in the Limpopo, Nile and Volta basins. The distribution of Theme 3 research across basins and issues is shown in Table 8.

CPWF projects typically address, or are "assigned", to more than one of the five CPWF Themes. The projects described in this section have large assignments to Theme 3. With two exceptions, these projects have only negligible assignments to other Themes, as may be seen in Table 9.

Questions and answers

Earlier in this section, several key questions were posed. Some questions are rather broad and perhaps can never be fully and definitively answered by the CPWF. Nonetheless, it is of some interest to assess the extent to which Theme 2 projects address these questions.

What are the factors that influence people's access to, and control over, aquatic ecosystems and their resources? Several Theme 3 projects highlight the extent to which different groups compete for access to and control over aquatic ecosystems. Some projects focus at the landscape level or below (PN30 on control of wetlands in dry environments) while others focus at much higher levels of analysis (PN52 on fisheries management across scales). These projects aim to provide decision support systems or even guidelines on resource access. The development of improved guidelines for access, however, presupposes that factors currently influencing access are well understood.

When and how can water productivity and livelihoods be improved by integrating fish production and the harvesting of other aquatic

animals and plants into farming and irrigation/ flood-prone systems? This question is addressed directly by projects 30 (the potential for fish culture in "dry environment wetlands" where there is strong competition for access); 34 (aquaculture in tropical reservoirs); 35 (introduction of aquaculture in irrigation systems and in seasonally flooded lands); and 10 (fresh- vs. saltwater aquatic systems).

What kinds of governance systems and enabling policies and institutions foster equitable and sustainable management of aquatic ecosystems? Governance systems are clearly addressed in projects 10 and 52. In addition, project 35 examines questions of governance systems, policies and institutions (some having to do with property rights) in managing aquatic resources in areas susceptible to seasonal flooding.

What are the appropriate tools for generating timely information for use by poor stakeholders? Most Theme 3 projects emphasize information generation – but these projects have not made much progress so far in answering the specific question of generating timely information for use by poor stakeholders. The question is of specific interest to project 52, a project that seeks to strengthen "governance systems for fisheries; policies and institutions for cross-scale management for use by community-based fisheries management institutions and local/national government institutions in the Lower Mekong countries [and] information and communication capacity of decentralized fisheries institutions."

What are the monetary and non-monetary values of goods and services provided by different types of aquatic ecosystems? This question is most clearly address by Project 30, where trade-off analysis seeks to assess the opportunity cost of using scarce aquatic resources in dryland areas in different ways, including the extent to which it may be possible to increase the use of wetlands to support people's livelihoods without compromising environmental security. As part of this project, a literature review has been compiled on the economic valuation of wetlands goods and services. This has been published as a conference paper.

Table 8: Distribution of issues across basins, Theme 3

Basin	Indus-Ganges	Limpopo	Mekong	Nile	Volta
Managing wetlands in dry environments					
Managing fisheries in tropical reservoirs					
Managing fisheries in irrigated fields, floodplains and deltaic lowlands					
Managing the saline - freshwater interface in coastal areas					
Fisheries management across scales					

Table 9 : Distribution acrossThemes of project s with a large assignment to Theme 3

Issues and projects	Theme 1 –	Theme 2 –	Theme 3 –	Theme 4 –	Theme 5 –
Managing wetlands in dry environments (PN30)					
PN30: Wetlands-Based Livelihoods in the Limpopo Basin: Balancing Social Welfare andEnvironmental Security	10%	30%	30%	30%	
Managing fisheries in tropical reservoirs (PN34)					
PN34: Improved Fisheries Productivity and Management in Tropical Reservoirs	5%	10%	70%	10%	5%
Managing fisheries in irrigated fields, floodplains and deltaic lowlands (PN35)					
PN35: Community-Based Fish Culture in Irrigation Systems and Seasonal Floodplains	10%		60%	20%	10%
Managing the saline - freshwater interface in coastal areas (PN10)					
PN10: Managing Water and Land Resources for Sustainable Livelihoods at the Interface between Fresh and Saline Water Environments in Vietnam and Bangladesh	50%		50%		
Fisheries management across scales (PN52)					
PN52: Strengthening Fisheries Management Institutions in the Lower Mekong River Basinthrough Collaborative Research and Data Synthesis across Multiple Scales			100%		

Theme 4 – Integrated basin water management systems

In this section, the focus of attention shifts to the basin as a whole, and to the integrated management of its water resources. Within a river basin, water resources become available and are used for a succession of purposes. These may include the production of plants, animals and fish; rural and urban direct consumption; industrial use and power generation; river transport; and the preservation of wildlife habitat and ecological processes. There are therefore many competing uses and users of water.

There may also be sizeable opportunities for enhancing water productivity through multiple and sequential uses of water as it cascades through the basin. Effective water resource management at the basin scale takes account, to the extent possible, of medium- to long-term processes of change, e.g., population growth, migration, urbanization, economic growth, opportunities for water development, water quality changes, etc.

Purpose and approach

Research under Theme 4 seeks to develop interventions aimed at improving livelihoods and conserving the environment through sustainable increases in basin level water productivity. This is achieved by generating, disseminating and applying an integrated knowledge base on:

- The biophysical and socio-economic context (current and future water availability and demand)
- Peoples' livelihoods and how they influence and are influenced by water quality and quantity
- How water and other natural resources are allocated among different users, the governance processes underpinning allocation decisions, and the consequences of water allocation for livelihoods, equity, food security, and public health
- Opportunities and constraints to the enhancement of water productivity in different parts of the river basin and the technological, managerial, policy and institutional innovations needed (at farm, community, sub-basin, basin and national level) to do so in ways that benefit the poor and the environment
- Targeting interventions – what works where, pre-conditions for success and minimum intervention packages

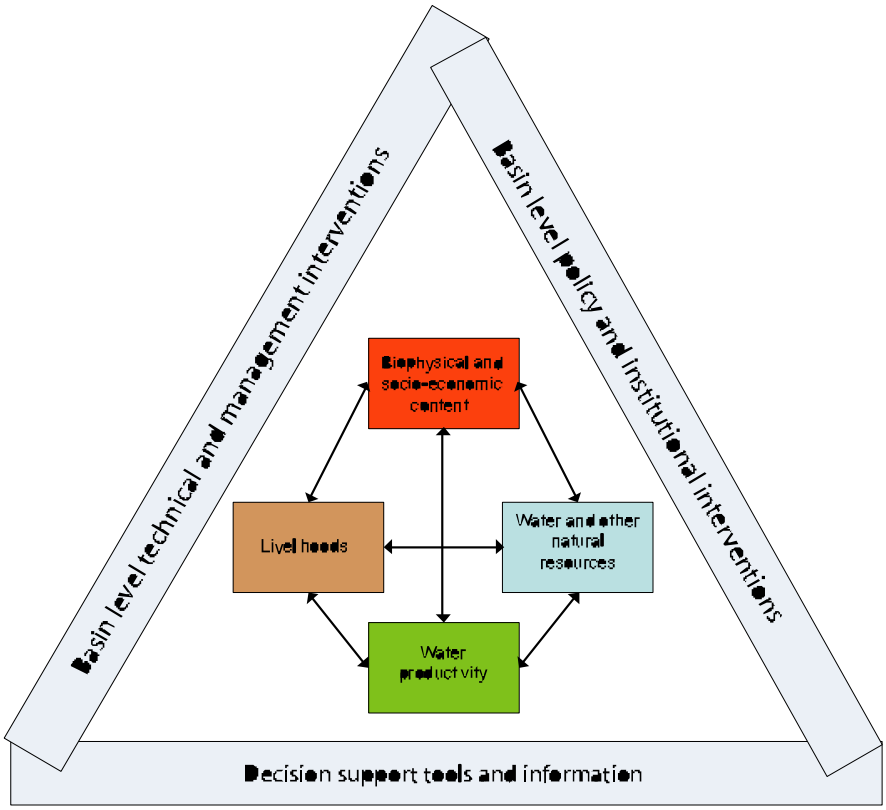
This information is used to promote the adoption of holistic and integrated water resources management approaches that optimize basin-level as well as farm-level benefits.

Increasing basin level water productivity is here interpreted broadly as achieving high incomes, higher yields, and/or more jobs per unit volume of water (available, used or depleted) in crop, livestock, tree and fisheries production in ways that benefit the poor and marginalized communities and the environment. In this context, here are some ways to improve basin level water productivity:

- Protecting water catchments, water resources and freshwater ecosystems (since productivity declines as resources are degraded);
- Fair sharing of water resources and cost/benefits associated with the use of these resources (to ensure that productivity gains are not just targeted to the better-off individuals and communities);
- Demand management by increasing output/ income per unit volume of water; and
- Augmenting supply and improving access through (a) water storage and conveyance infrastructure; and (b) use of marginal quality water resources (saline water and wastewater).

Integrated basin water management system consists of internal processes determined by natural factors and individual and community level actions in different parts of the basin. The processes and outcomes are also influenced by global and national drivers of change. The elements of integrated basin water management systems are portrayed in Figure 4.

Figure 4: Key elements of integrated basin water management systems



Research areas, key questions, issues and projects

Although patterns of water use at the basin level are typically influenced by many factors, well-informed decision-making on water resources protection, allocation, development and use can result in more desirable outcomes. The very notion of integrated water resource management within a basin implies a conscious effort to improve water resource management so that it more effectively contributes to the achievement of particular goals, e.g., less poverty, increased food security, enhanced human health, and environmental preservation. Decisions that affect the ways in which water is managed – and the ways in which these decisions are taken – can have far-reaching consequences.

In this context, more, better, timely, appropriately packaged and targeted information can be of tremendous value. Policymakers and planners might be able to improve their decision-making if they had easier access to better information on the basin-level consequences of different water allocation strategies. Much of the work under Theme 4 (and related work under Themes 2 and 5) aims to strengthen this decision-making process through the development and application of decision-support tools, and the analysis and improvement of governance mechanisms.

As is the case for the other Themes, CPWF activity within Theme 4 is implemented through projects that are associated with research areas identified during research planning. Projects are intended to help answer key questions. In this synthesis, projects are further grouped according to the issue being addressed. Theme 4 research is heavily concentrated in sub-Saharan Africa, especially in the Volta basin.

The main question guiding research in this Theme is, "*How can basin stakeholders sustainably enhancing human well –being (livelihood, food and*

health securities) and ecological well-being (environmental security), concomitantly, through increases in basin level water productivity?"

To answer this key question, Theme 4 research is organized around three research areas.

1. Innovative technological and management solutions. To protect water resources from degradation; help augment water supplies; manage demand; alleviate constraints to agricultural growth through improved infrastructure; enhance water productivity; rehabilitate degraded ecosystems; and/or cope with floods and droughts.

2. Effective policies and institutional arrangements. To improve governance of water and other natural resources; to strengthen institutions; and to help facilitate the adoption of appropriate technologies and management strategies that contributes to improved basin-level water productivity and the achievement of other shared social goals.

3. Decision support tools and information. To synthesize information from different sources to help inform decision-making on complex issues such as setting goals and targets, assessing trade-offs, evaluating alternative strategies, and facilitating effective participation of marginalized stakeholders.

Four key questions were posed. Work in all three research areas is needed to answer them.

- What is the status of water resources (quality and quantity) in different parts of the basin, what are the emerging threats and how can the threats be addressed?
- How are water allocated among uses and users, how are benefits/costs associated with water resources shared, what is the impact of allocation and sharing arrangements on poverty gap, livelihoods and food security and how can improved governance, information on trade-off, and negotiations tools facilitate participatory decisions making on fair sharing of water resources and cost/benefits arising of the use of water resources?
- Are there additional water resources be tapped to augment the current supplies and how can they be tapped with minimize adverse social, economic and environmental impacts?
- What are the opportunities for increasing water productivity in different parts of the basin, what will be the associated social, economic and environmental impacts; would they increase overall basin level water productivity and what adaptive management measures would need to be put in place to tap these potentials sustainably?

Issues are implicit in the above discussion on integrated water resource management. Projects focus primarily on one issue though, in keeping with the integrated nature of Theme 4, some of them occasionally also touch on other issues. Issues include:

1. Increasing basin-level water productivity to reverse water resource degradation (projects 5, 17, 23, 30, 37)

2. Improving governance processes affecting basin-level water resources (projects 25, 36, 40, 42, 47, 50)

3. Increasing the level of water resources available in a basin (projects 7, 10, 36, 38, 46)

Relationships among Theme 4 issues and research areas are shown in Table 10.

Increasing basin-level water productivity to reverse water resource degradation

Water and land quality concerns are increasing in many developing countries. This issue focuses on positive and negative on-site and off-site impacts associated with water movement through a basin. Forest ecosystems play a key role in protecting water catchment thereby providing vital hydrologic functions. Crop and grazing land can also provide these functions if they are managed in ways that favor a suitable storage and flow of surface and groundwater resources.

Table 10: Relationships between issues and research areas, Theme 4

Research area	Issue 1. Increasing basin-level water productivity to reverse water resource degradation	Issue 2. Improving governance processes affecting basin-level water resources	Issue 3. Increasing the level of water resources available in a basin
Innovative technological and management solutions	Soil resources conserving technologies and management practices Forest, grassland and wetland management practices that reduce land degradation and encroachment on pristine ecosystems	Water allocation and re-allocation mechanism	Small reservoir water storageInter-basin (or sub-basin) water transferWater convey-ance infrastructureRural development infrastructureWaste water and saline water based crop and fisheries production systems
Effective policies and institutional arrangements	Policies and institutions influence the direction and efficiency with which water-saving practices are developed.	Policies and institutions affect the efficiency with which water allocation decisions are made.	Policies and institutions drive decision-making on investments in water resource development.
Decision support tools and information	Decision support tools and information underpin everything else. They are critically important for efficient technology development and effective decision-making.		

Water pollution and degradation of freshwater ecosystem are becoming serious problems in many river basins. Agricultural intensification (featuring an increased use of fertilizers and pesticides), and expansion of agriculture into steep sloping forest lands and wetlands, are the major sources of non-point pollution of water resources. As urbanization and industrialization increases, the threat of industrial and urban pollution increases. Water-borne pollutants are deposited in wetlands where they degrade the freshwater ecosystems, resulting in a decline in the productivity of the aquatic ecosystems.

Several CPWF research projects work towards improving agricultural water productivity at the plot, farm or catchment level, and in this context have already been discussed in previous sections. These same projects also have relevance to Theme 4 when they examine the extent to which improvements in water productivity at the farm, field or catchment levels also contribute to improvements in water productivity at the basin level and to reduced non-point pollution from agriculture. Understandably, these Theme 4 projects tend also to be assigned to Themes 1 and 2, but rarely to Themes 3 and 5. As it happens, most of these projects are located in Africa.

The **Volta** basin project (5) focuses on increasing rainfed agricultural water productivity through water harvesting systems and soil-water-plant-nutrient management practices. These include the "Sahelian Eco-Farm", fertilizer micro-dosing, and the use of "zaï" and other planting pit technologies. Progress in developing these technologies was described in the section on Theme 1.

Basin-level water productivity will rise to the extent that widespread adoption of these practices results in more water being productively used by farmers' crops, with less water being unproductively depleted, e.g., through evaporation or pollution-creating run-off. Basin-level environmental consequences may be favorable insofar as the new technologies reduce land and water degradation.

In principle, widespread adoption of these technologies might have a significant hydrologic and water quality impacts. The field experimental data that this project is collecting will be used to evaluate basin level impact of dry season water flow and of water quality using a combination of DSSAT and SWAT models. To date, however, it remains unclear whether reduced run-off in catchments will, overall, have harmful or beneficial downstream consequences. So far, this project has not begun to assess the basin-level consequences of farm-level interventions.

The **Limpopo** basin project 17 is working on similar problems. Water resources are certainly becoming scarcer – preliminary studies show a trend of declining rainfall and runoff in parts of basin while modeling of future runoff suggests that the problem will only get worse. The project team perceives an urgent need to develop technical and institutional innovations to cope with this threat. So far, the team has conducted surveys in the Mzingwane Catchment to assess the effect of different rainwater harvesting systems (WHS) on water productivity. Survey results are being used to understand and further improve farmers' WHS.

These technologies (and the challenge of fostering their widespread use through participatory technology adaptation) were described in the context of Theme 2. As with the Volta basin project, water productivity at the basin level will rise to the extent that WHS result in reduced water depletion through evaporation and reduced pollution-creating runoff. In this project, however, there are specific plans for monitoring the impact of technical change on water productivity in catchments, and water availability elsewhere in the basin. These plans include the study of trade-offs between upstream and downstream water users, as well as options for improved downstream irrigation efficiency.

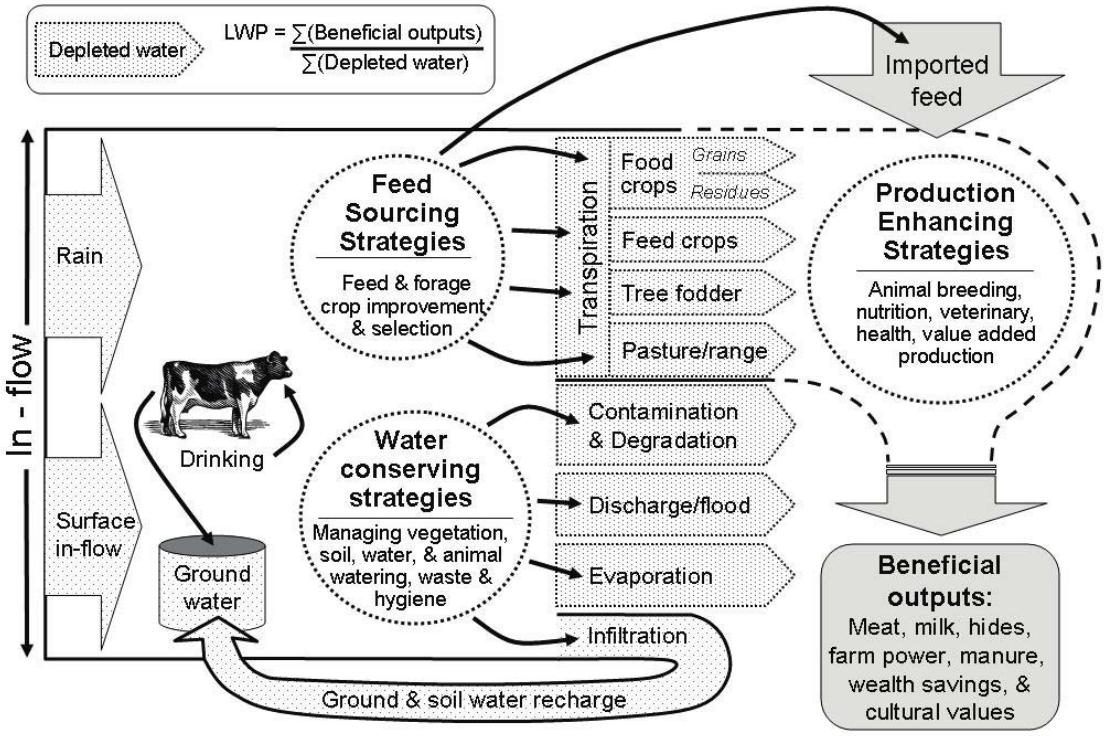
Another project in the **Limpopo** (project 30) focuses on wetlands. It aims to analyze trade-offs among crop, livestock and fisheries water use strategies in "dambo" lowlands and riverine swamps. As described in the context of Themes 2 and 3, this project uses models as a "framework for analyzing trade-offs between food production/ security and environmental security" – specifically the trade-offs among alternative mixtures of agricultural (crop and livestock) and fisheries water-use strategies in dambos and riverine swamps. The intent is to draw on model outcomes to develop guidelines for wetland utilization. Although the project analyzes trade-offs associated with alternative uses for wetlands, it is not clear to what extent it assesses possible consequences for downstream water users.

Project 30 addresses this issue by generating information on the effects of alternative wetland based livelihood strategies on livelihood outcomes and sustainability of the goods and services derived from different types of wetland in the Limpopo basin. The project is also collecting data that will be later used in assessing hydrologic, ecological and social linkages of wetlands in a basin. This will form the basin for guidelines on how to manage wetlands in a basin context so as to sustain their hydrologic and water quality functions.

Project 37 is studying livestock production systems in the Nile basin so as to identify the potential for increasing livestock outputs, profitability and productivity sustainably. Their analysis of livestock related land and water quality degradation issues will contribute in addressing water catchment degradation issues. This project is also collecting data that will be used in simulating the hydrologic, soil erosion and water pollution impacts of livestock production of different technological and management interventions.

Livestock water productivity is the topic of an innovative CPWF project (37) located in the **Nile** basin. A livestock water productivity framework has been developed (Figure 7) which will be used to track the production of beneficial animal products and services (e.g., meat, milk, hides, animal power); water in-flow and depletion pathways; and how these are affected by alternative livestock management strategies.

Figure 5: Conceptual framework for assessing livestock water productivity[12]



By understanding the inputs and outputs of various sub-systems and the factors that constrain them, livestock scientists and practitioners can develop more appropriate water-conserving, feed-sourcing and production-enhancing strategies. Work is now beginning on baseline data collection on livestock water interactions.

The project has already had one kind of impact: Many stakeholders have gained an enhanced understanding of the importance of livestock water productivity concepts. Among these are scientists and staff from IWMI, FAO, and several NGOs and East African NARES. There are plans to apply in the future the livestock water productivity framework at the basin level.

Finally, project 23 in the **Indus-Ganges** basin is exploring policies and institutional arrangements for reducing pressures on forest resources thereby reducing the threat of water pollution associated with forest degradation in the steep sloping areas of Nepal in the Indus-Ganges basin. This project is generating information on community level water, land and forest resource flows, needs and management regimes and impacts of alternative management strategies on human well-being (food security and livelihoods) and ecological well-being (reduced forest and water resource degradation).

In summary there appears to have been only modest progress – so far – in assessing the basin-level water productivity and pollution-reducing consequences of plot- or catchment-level technologies – at least for these particular projects. Table 11 portrays the progress in assessing plot-level vs. basin-level water productivity for the projects discussed above.

How, then, are these projects contributing to the Theme 4 research agenda? In their early stages, these projects are focusing on local level issues

[12] Source: CPWF. 2006. Theme 4: Crop Water Productivity Improvement 2005 Synthesis Report

Table 11: Progress in assessing plot- vs. basin-level water productivity, Theme 4[13]

Project	Basin	% assignment to Theme 4	Plot- or catchment-level improvements in water productivity	Basin-level consequences of water productivity improvement at the plot or catchment level
PN5	Volta	30%		
PN17 [1]	Limpopo	32%		
PN30 [2]	Limpopo	30%		
PN37 [3]	Nile	50%		

associated with crop and livestock production. This will form the basis for identifying what works, under what biophysical conditions and what combination of technologies and management practices achieve the desired levels of productivity and livelihood outcome? Basin level analysis of the impact of hydrologic, ecological, social and economic impacts of the interventions proposed by these projects will be carried on later using a combination of simulation models. This will be followed by an analysis of policy and institutional requirements for scaling up these interventions within the basin. Currently, project 5 and project 37 researchers are assessing DSSAT and SWAT models respectively. It is also envisaged that Basin Focal Projects will evaluate the suitability of these interventions in other basins.

Improving governance processes affecting basin-level water resources

One of the issues discussed under Theme 2 was the possibility that water productivity in catchments might be improved through the voluntary reallocation of water resources from low- to high-productivity uses. The argument was made that,

> "For this to happen consensually, it must be founded on agreements amongst stakeholders – agreements that are best forged through informed debate, and shaped so that everyone benefits. The efficiency of this debate, and the suitability of proposed agreements, can be enhanced through a combination of stakeholder analysis, modeling, scenario analysis, and the application by stakeholders of decision-support systems."

The same argument may be made at the level of the whole river basin. There may be win-win opportunities for reallocating water resources among the entire range of possible uses in a basin: rainfed agriculture in upper catchments, irrigated agriculture downstream, rural and urban direct use, industrial use, hydropower generation, riparian navigation, fisheries and aquatic systems, and even environmental and ecological uses.

In going from the level of the catchment to that of the basin, of course, there is likely to be a vast increase in the number of stakeholders, the range of their interests, the complexity of modeling and scenario analysis, and the challenge of fostering fully inclusive stakeholder dialogue There may even be transboundary questions involving multiple governments (discussed in Theme 5).

[13] Green = substantial progress; yellow = little progress; gray = undetermined.

[14] Work has focused on consequences of climate change for urban water supplies and the impacts of drip irrigation kits on farmers' livelihoods.

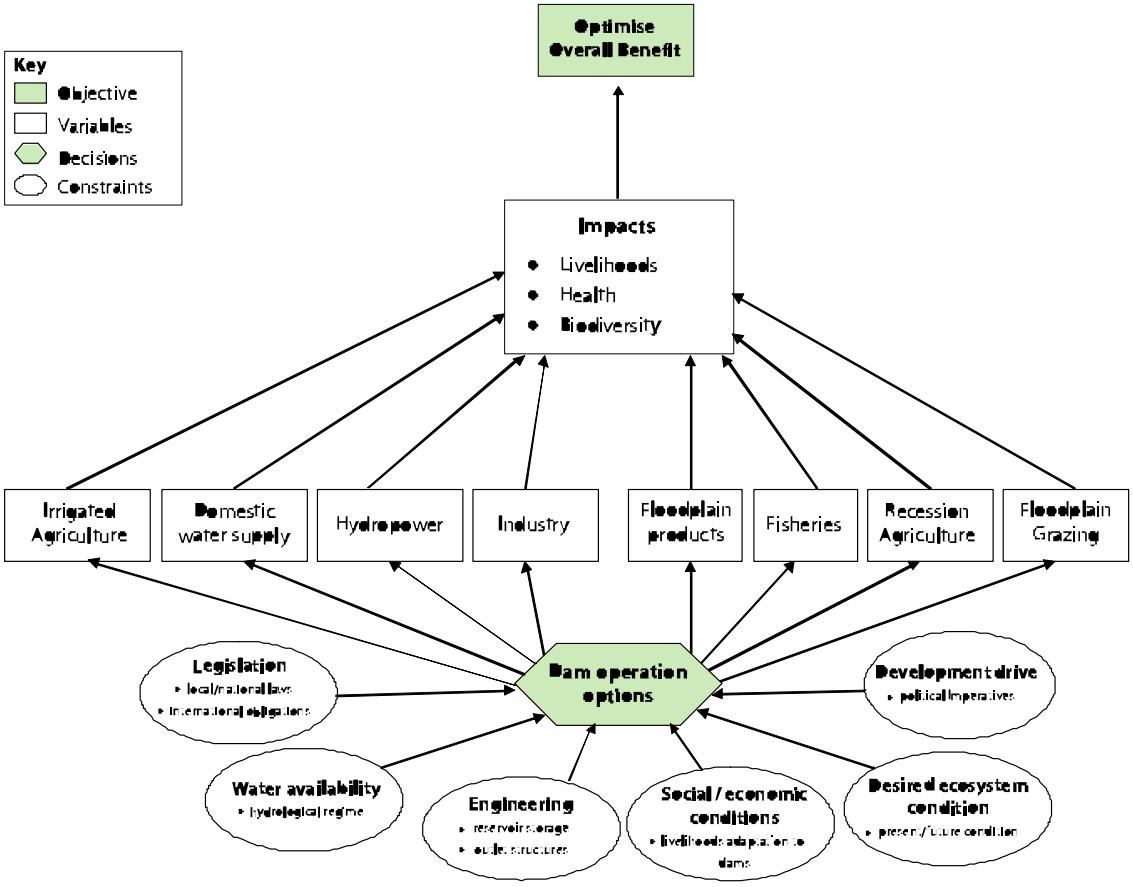
[15] Work has focused on water allocation and implications for water productivity in the context of particular wetland areas, but as yet not on the downstream consequences of such changes in water allocation.

[16] Work has focused on water productivity in livestock production. Plans have been announced to apply the livestock water productivity framework at the basin level, but little progress was made on this during 2005.

Three CPWF projects are attempting to deal with this immensely complex issue. The first of these, PN36, looks at the use of decision-support systems in the **planning and operations of large dams** in the **Nile** basin. The underlying assumption of PN36 is that the productivity of water stored in dams can be improved through planning and management of these structures in ways acceptable to stakeholders.

The conceptual framework for this project, shown in Figure 5, portrays several trade-offs whose effects may need to be evaluated and considered during stakeholder consultation and dialogue. Decision support tools being developed by this project aim to facilitate stakeholder participation in priority-setting, the evaluation of trade-offs, and the use of multi-criteria decision analysis.

Figure 6: Conceptual framework for dam planning and operations



During 2005, the project held its inception workshop, began a survey of dam planning and operation guidelines from countries around the world, organized an international conference/ workshop, and began work with MSc and PhD students on decision support systems for dams in the Nile basin.

Whereas PN36 focused on dam planning and operation, project 42 focuses on groundwater governance, specifically in the Indus-Ganges and Yellow River basins. These two river basins share several common factors: they are densely populated (over 2 billion people live in the two basins); they are home to large numbers of the

very poor; they have vibrant groundwater economies, and they have areas where groundwater depletion has reached crisis levels.

Project 42 has developed an innovative approach that will be used to engage key actors drawn from government, civil society, media and academia in an inter-disciplinary program of training and policy research in groundwater governance. They have developed a conceptual framework that links studies on resource behavior, groundwater users, groundwater institutions and global best practices as a basis for developing a toolkit for groundwater governance (see Figure 6).

The major task of this project is the development and delivery of the international and multi-disciplinary training program on "Groundwater governance in theory and practice" to be delivered during two cycles, the first on in the period October 2006 – March 2007. Parallel, and partly integrated within this task, is the development and implementation of pilot studies and synthesis research related to groundwater management.

The Project was launched in April 2005 with an inception workshop. As part of project launch, and in response to recommendations emerging from the inception workshop, a "Sensitization Tour" to all five project countries was scheduled for late 2005. The objectives of the Sensitization Tour were to:

- Meet and initiate collaboration with organizations and institutions involved in groundwater management, research and media coverage that may provide fellows and participate in research within the project
- Present the project, its scope and to advocate for active involvement and commitment
- Present a draft proposal for a research agenda for the project
- Make initial steps towards recruiting the fellows for the courses
- Get feedback from the institutions in terms of capacity building needs and priority research topics that could prove valuable in the more detailed planning of the courses and the research.

The first sensitization meeting was held in Zhengzhou, China from 16 to 24 October 2005.

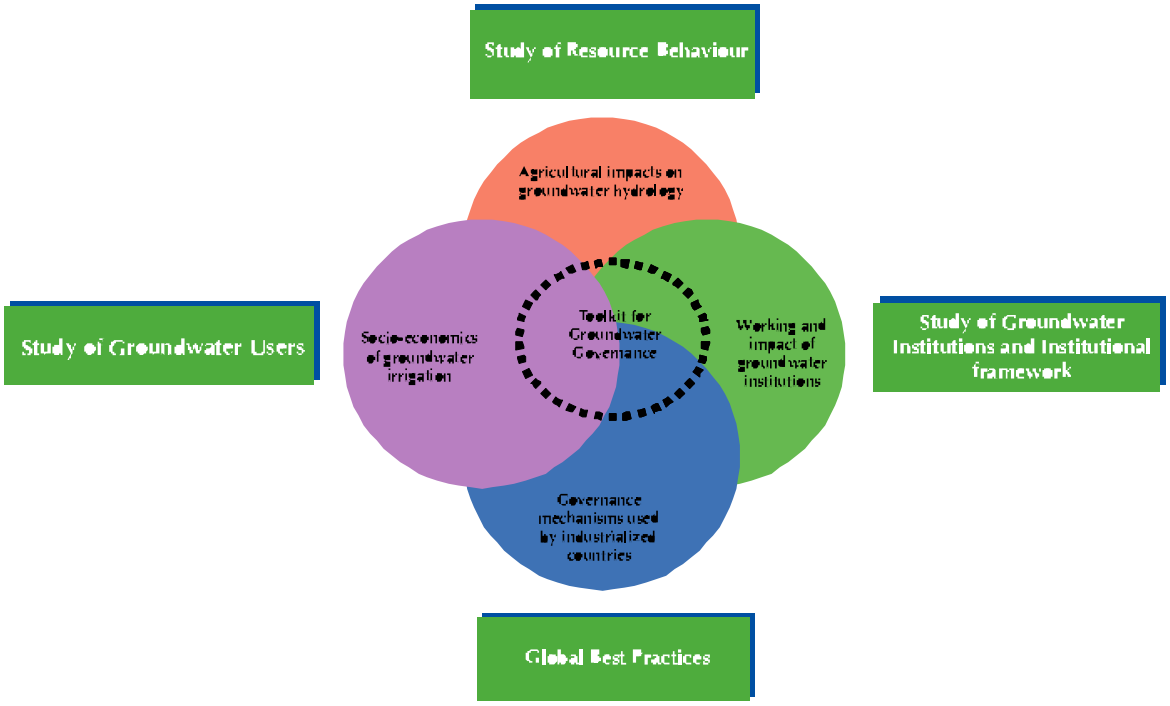
Finally, project 40, working in the **Andean** and **Volta** basins, takes the broadest possible approach. It aims to strengthen **multi-stakeholder governance structures** in two project sites, one in Ghana and one in Chile. Governance structures are thought to be important because they are the venue where negotiations occur at the sub-basin level on questions of water allocation. These structures are to be strengthened by identifying problems, shaping policy options, and establishing criteria for their evaluation by stakeholders. (Project 40 was introduced in the context of Theme 2).

Initial project activities feature "an analysis [and mapping] of the existing multi-stakeholder governance structures which will lead to the establishment of an institutional platform for the exchange of scientific and local knowledge". The purpose of this analysis is to identify relevant stakeholders/ decision makers and the flow of water-related information amongst them, and then to integrate this information into model development and a corresponding research and learning framework.

Stakeholder evaluation of policy options is to be assisted by a simulation model capable of "predicting agent-agent and agent-environment interactions". The simulation model in question integrates a climate model, a hydrological model and an agent-based socio-economic model. Decision support tools are to be designed that will allow stakeholders to better visualize the outcomes of different simulation scenarios. The intent is to use these decision support tools during actual processes of negotiation and planning within the governance structures in question.

During 2005, the project 40 project team made progress in analyzing governance structures and identifying stakeholders in the two project areas. Workshops were held to identify stakeholders' problems and information needs. Household, community and water-use association surveys were completed, agent behavior in the model was updated and calibrated, and progress was made in the parameterization and sensitivity analysis of the hydrological components of the multi-agent model.

Figure 7: Conceptual framework for groundwater governance



Increasing the level of water resources available in a basin

One way around water scarcity is to develop "new" sources of water. This is not always easy (or else water scarcity would rarely be a problem). The most straightforward way to increase water availability is to invest in water resource development, e.g., through large (and often controversial) projects involving the construction of dams, irrigation systems, or groundwater development schemes. Projects of this kind are discussed in Theme 5.

Theme 4 projects explore the following strategies used for increasing available water resources and its access by the poor are:

- Developing ensembles of small, multi-purpose reservoirs (project 36 and project 46)
- Fostering the safe and productive use of wastewater (project 38)

Project 36, discussed earlier, explores dam planning and operation issues and is developing guidelines on how dams can be operated to optimize benefits and reduce conflicts associated with competing uses. CPWF project PN46 focuses on this issue, taking a holistic approach to water storage in the **Volta, Limpopo** and (to a lesser extent) the **Sao Francisco** basins. It studies ensembles of small reservoirs in a sub-basin to ascertain economic, social, health, hydrologic and ecological impacts of different "densities" of reservoirs in a given area. These impacts include effects on environmental flows, the downstream availability of water resources to riparian countries, and overall river basin water productivity. To develop these insights, the project is developing methods and tools for assessing hydrologic, ecological, water quality, health, and livelihood impacts.

Progress to date in the Limpopo basin to date includes: the development of a database of small reservoirs in the study areas; the construction of a model that allows the estimation of reservoir volume from remote sensing /GIS estimated surface areas; the assessment of ecosystem health of selected small reservoirs; and the incorporation of the

appropriate information on small reservoirs into WEAP (a water resources management and allocation model) allowing economic analysis of different small reservoir development and management scenarios.

In the Volta basin, progress has been made on understanding reservoir ensemble hydrology, in part through the development of a virtual "equivalent" reservoir that fills and empties just as a reservoir ensemble does, and therefore can be used in water allocation models such as WEAP. Detailed measurements of water use revealed very different levels of Relative Water Supply (RWS) at two reservoirs in close proximity to one another. This finding suggests that institutions and management practices at reservoirs can result in markedly different outcomes even though farmers' biophysical and economic circumstances are similar.

Two CPWF projects (38 and 51), both in the **Volta** basin, are working to augment the safe, productive use of **wastewater**. Project 38 addresses health issues associated with consumption of vegetables irrigated using wastewater. Its area of activity covers the cities of Accra, Kumasi and Tamale in Ghana and Burkina Faso. The project aims at developing effective but simple strategies to safeguard public health without compromising the livelihoods of urban farmers. Such strategies embrace the development of alternative water sources, on-farm wastewater treatment methods, alternative irrigation practices and cropping patterns, and post-harvest handling methods. As part of strategy development, information is being gathered on current land and water use practices in urban and peri-urban vegetable farming, water pollution, vegetable contamination (and decontamination) along marketing pathways, and the effect of different management strategies on vegetable quality.

To date, project researchers have surveyed sources of wastewater (wells, septic tanks, bio-digesters, sand-filters, lagoons, etc.) and have identified and assessed alternative farmer-developed risk reduction measures. They have also concluded that it will not be economically prudent to invest in developing groundwater resources in these areas using capital-intensive drilling techniques (although manual, low-cost shallow tubewell installation may be viable under some circumstances).

Project 51 works in close collaboration with project 38, focusing largely in the same locations in the **Volta** basin. This project has emphasized the detailed assessment of the contamination of vegetables, especially lettuce, along the marketing chain. In a study informally labeled "Who eats lettuce?" it was found that in Accra and Kumasi, street food venders, not private households, were the principal purchasers. Samples of lettuce were taken from producers' fields, market stalls, and street vendors and analyzed for microbiological contamination (bacteria, protozoan parasites, and worm eggs and larvae). Levels of contamination were found alarmingly high – far above WHO recommendations – and in some instances, contamination levels were found to increase along the production – consumption pathway, suggesting that wastewater is not the only factor contributing to crop contamination.

Agricultural productivity in area with saline soil and/or water resources can be enhanced by developing appropriate technologies and management practices that facilitates crop and fish production in these environments. Project 7 and project 10 under, Crop Water Productivity Improvement theme are tackling that challenge by exploring possibilities of augment basin water resource availability by making more productive use of saline water. Project 7 seeks to enhance land and water productivity of rice-based cropping systems in salt-affected areas through integrated genetic improvement and soil and water management strategies. Project 10 is exploring fish-crop farming systems appropriate for coastal zones of Mekong and Ganges basins. In Bangladesh, the project is assessing the salinity of surface and groundwater and suitability for irrigation and shrimp production. The research findings of this project will be used by IBWMS theme to explore recommendation domain of these technologies and management strategies in Indo-Gangetic, Mekong and Nile basins.

Issues and basins, projects and themes

The distribution of Theme 4 projects across issues and basins is somewhat curious. All projects working on "Increasing the level of water resources available in a basin" are located in sub-Saharan Africa, and only in the Volta basin. Nearly all projects working on "Increasing basin-level water productivity to reverse water resource degradation" are also located in sub-Saharan Africa. It is only with the issue of "Improving governance processes affecting basin-level water allocation" do non-African basins appear – and most of these are projects that have a large assignment to Theme 5 as well as Theme 4. The distribution of Theme 4 projects across issues and basins is shown in Table 12.

Many CPWF projects are assigned to multiple Themes. The projects described in this section have large assignments to Theme 4. With few exceptions, these projects also have large assignments to other Themes, and this varies by issue: Theme 4 projects working on the issue of "Generating basin-level benefits from farm-level interventions" are also assigned to Themes 1 or 2. In contrast, Theme 4 projects working on the issue of "Improving governance processes affecting basin-level water allocation" are also assigned to Theme 5. This is shown in Table 13.

Questions and answers

Earlier in this section, four key questions were posed. To what extent do Theme 4 projects address these questions? Each question is listed and discussed in turn.

What is the status of water resources (quality and quantity) in different parts of the basin, what are the emerging threats and how can the threats be addressed? All Theme 4 projects are attempting to understand the status of water resources in the basin but not in a comprehensive manner. For example, projects addressing governance issues are addressing this question with respect to how water availability intensifies water competition and affects the performance of governance mechanisms. PN5, PN23 and PN37 are exploring how crop, tree and livestock production systems affect water availability and quality, respectively. PN37 has identified hotspots in the Nile basin and is exploring soil, water and grazing management practices that can contribute in the rehabilitation of the degraded area.

How are water allocated among uses and users, how are benefits/costs associated with water resources shared, what is the impact of allocation and sharing arrangements on poverty gap, livelihoods and food security and how can improved governance, information on trade-off, and negotiations tools facilitate participatory decisions making on fair sharing of water resources and cost/benefits arising of the use of water resources? This set of questions is addressed by six Theme 4 projects. The project have highlighted the key issues in Volta, Limpopo, Nile, Indo-Gangetic, Mekong and Yellow river basins, formulated the conceptual frameworks, and are now mainly collecting data and developing tools for the analysis.

Are there additional water resources be tapped to augment the current supplies and how can they be tapped with minimize adverse social, economic and environmental impacts? Five projects are exploring opportunities for enhancing water availability – small reservoir, use of urban wastewater and crop and fish production in saline environment. The potential contribution of these strategies to poverty alleviation has been highlighted. A set of technologies and management practices are currently being evaluated.

What are the opportunities for increasing water productivity in different parts of the basin, what will be the associated social, economic and environmental impacts, would they increase overall basin level water productivity and what adaptive management measures would need to be put in place to tap these potentials sustainably? The five Theme 4 projects working on this question are evaluating promising technologies and management strategies for enhancing local level water productivity in different parts of Volta, Limpopo, Nile, and Indo-Gangetic basins. They are also gathering the data required for analysis of basin level hydrologic, social, economic and environmental impacts.

Table 12 : Distribution of project s across issues and basins, Theme 4

Issues	Andes	Indus-Ganges		Limpopo		Mekong	Nile		Volta						Yellow
	PN40	P23	P42	PN17	PN30	PN50	PN36	PN37	PN5	PN38	PN46	PN51	PN40	PN47	PN42
Increasing basin-level water productivity to reverse water resource degradation		■			■			■	■						
Improving governance processes affecting basin-level water allocation	■		■			■	■						■	■	■
Increasing the level of water resources available in a basin										■	■	■			
Generating basin-level benefits from farm-level interventions				■	■			■	■						

Table 13 : Distribution across Themes of project s with a large assignment to Theme 4

Domains and project	*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 – The Global food and water system*
Increasing basin-level water productivity to reverse water resource degradation (PN 5, 17, 23, 30, 37)					
PN05 – Enhancing Rainwater and Nutrient Use Efficiency for Improved Crop Productivity, Farm Income and Rural Livelihoods in the Volta Basin	50%	10%		30%	10%
PN23 – Linking Community-Based Water and Forest Management for Sustainable Livelihoods of the Poor in Fragile Upper Catchments of the Indus-Ganges Basin	20%	50%		20%	10%
PN30 – Wetlands-Based Livelihoods in the Limpopo Basin: Balancing Social Welfare and Environmental Security	10%	30%	30%	30%	
PN37 - Increasing Water-Use Efficiency for Food Production through Better Livestock Management - The Nile River Basin	30%	20%		50%	
Improving governance processes affecting basin-level water (PN 36, 40, 42, 47, 50)					
PN36 – Improved Planning of Large Dam Operation: Using Decision Support Systems to Optimize Livelihood Benefits, Safeguard Health and Protect the Environment			20%	80%	
PN40 – Integrating Knowledge from Computational Modeling with Multi-Stakeholder Governance: Towards More Secure Livelihoods through Improved Tools for Integrated River Basin Management		40%		50%	10%
PN42 – Groundwater Governance in Asia: Capacity Building through Action Research in Indo-Gangetic (IGB) and Yellow River (YRB) Basins		10%	5%		50% 35%
PN47 – Transboundary Water Governance for Agricultural and Economic Growth and Improved Livelihoods in the Limpopo and Volta Basins: Towards African Indigenous Models of Governance [total does not sum to 100%]	10%	10%	5%	40%	40%
PN50 – Multi-scale Mekong Water Governance: Inter-disciplinary Research to Enhance Participatory Water Governance from Local Watershed to Regional Scales		5%	10%	5%	40% 40%

Increasing the level of water resources available in a basin (PN 38, 46, 51)					
PN38 – Safeguarding Public Health Concerns, Livelihoods and Productivity in Wastewater Irrigated Urban and Peri-Urban Vegetable Farming in Ghana				100%	
PN46 Planning and Evaluating Ensembles of Small, Multi-purpose Reservoirs for the Improvement of Smallholder Livelihoods and Food Security: Tools and Procedures		25%	15%	50%	10%
PN51 - Waste water irrigation - opportunities and risks	20%			80%	

Theme 5 – The global and national food and water systems

The world is in the midst of unprecedented change. One dimension of this is globalization, characterized by the increased mobility of goods, services, capital, labor, information and technology throughout the world, largely driven by trade liberalization. Over the long term, globalization may generate significant economic benefits for developing countries. However, in the short term it can create economic and political instability, exacerbate inequities, and make the poor more vulnerable. Another dimension emerges from population growth, economic development and land use change. Processes of urbanization, the elimination of wetlands, and land and water degradation may undermine the world's capacity to feed a larger and wealthier population while also maintaining the environmental and ecological services derived from water resources.

Yet another dimension is climate change. The world is undergoing significant global warming and, with it, perturbations in regional and global water cycles. These shifts may undermine the capacity of agroecosystems to meet food needs and could trigger severe water shortages. Higher temperatures and the associated changes in hydrological regimes may shorten growing seasons, increase the frequency of extreme and destructive weather events, and shift the incidence of pests and diseases. These processes of global change will profoundly affect almost everything related to water and its management: the use of water in food production; the livelihoods of water users; rights and access to water especially by poor and marginalized people; the health of aquatic ecosystems; and the incidence and severity of conflicts over water use. The largest impacts from these changes will be on poor rural farmers, herders, and fishermen and women in developing countries.

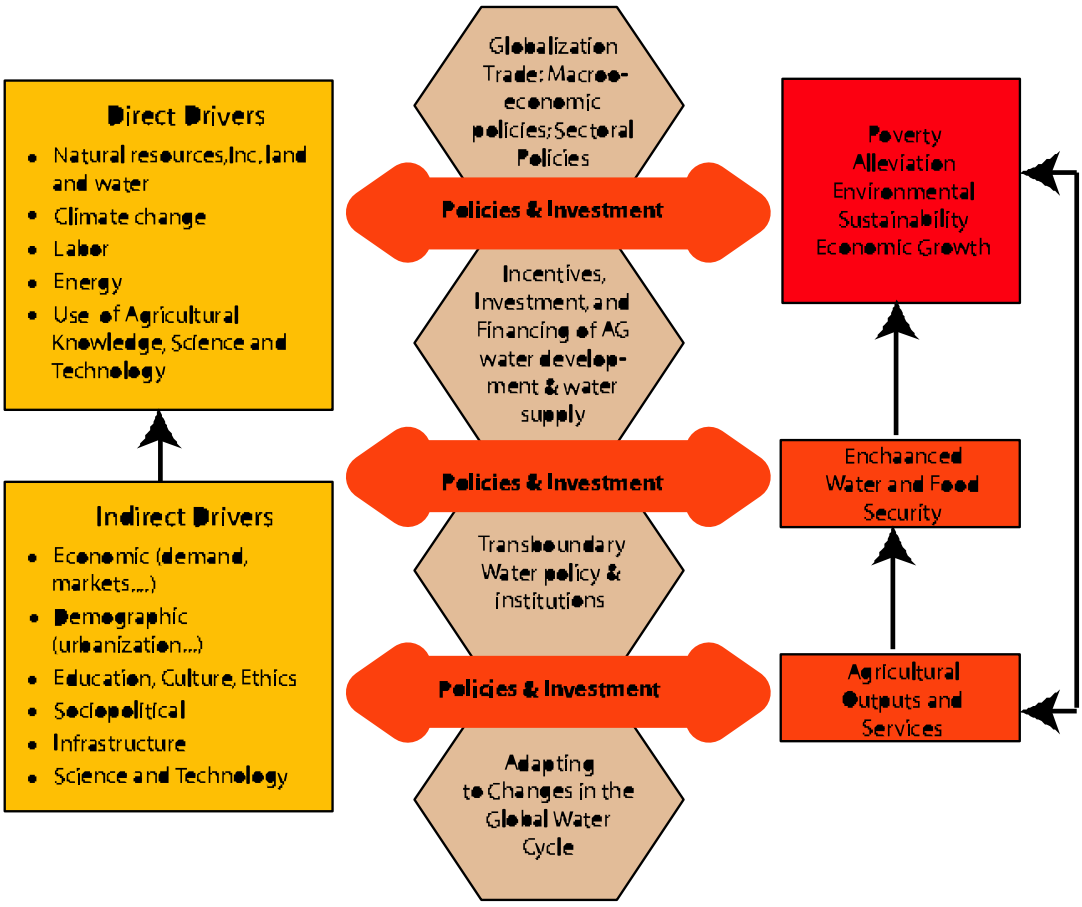
As these processes unfold, however, humanity is not merely a passive observer. International, national and regional policies and institutions are continuously evolving as a result of changes in underlying conditions, either reducing or amplifying positive and negative impacts from global change. It will therefore be crucial to identify policies and institutions that reduce adverse and harness positive features of global change for the poor. For example, trade regimes, investment trends, and incentives for water use can be shaped by policies and institutions, thereby influencing the fate and state of water resources.

The identification of appropriate policies and institutions requires improved knowledge of the complex interplay between global change and policymaking that affects the water sector, through the development of methodologies and tools that can support decision makers, and through the build-up of institutional capacity in this area. Research projects that fall under Theme 5 are designed to inform policy decisions to enhance food security and human health, to promote the production of more food with less water, to help alleviate poverty, and to protect ecosystems. Theme 5 focuses on two kinds of policies, and the links between them:

- Policies specific to the water sector, such as water institutions, economic incentives, and investment strategies
- Policies that lie outside the water sector, but indirectly affect water availability and quality, such as those on trade, climate, and macroeconomic issues

The conceptual framework used in for analyzing global and national food and water systems is shown in Figure 8.

Figure 8: Conceptual framework for analyzing the food and water systems[17]



Sub-themes, research questions, issues and projects

CPWF activity within Theme 5 is implemented through specific projects associated with research areas that were identified during the research planning process, and a series of key research questions were posed. For the purpose of this synthesis, projects for Theme 5 are further grouped according to the issue or problem that each one addresses. Because the overlap between Themes 4 and 5 is relatively large, issues for these two Themes are integrated into a unified framework.

The key research questions for Theme 5 include:

1) How can globalization and trade liberalization be managed to best enhance water and environmental policy and the management of water quality and water-related ecosystems?
2) What proportion and types of investment should be made in water development versus agricultural research, education, health and nutrition? How much money should be invested in dams, taking into account future water needs as well as the financial, social and environmental costs of dam building?

[17] Source: Theme 5 synthesis document for 2005.

3) How can broader goals, including agricultural development, rural livelihoods, food security, water quality, and health and nutrition, best be integrated into international river basin agreements?

4) How will changes in global water cycles affect food production and change the ways in which the poor, women and disadvantaged groups access ecosystem services? How can global and national policies and institutions prevent or mitigate the negative impacts of changes in global water cycles on water and food security and on the livelihoods of the poor, women and the socially excluded?

The four research areas analyzed by Theme 5 are derived from the key research questions and can also be seen in Figure 8. They are:

1. Developing suitable globalization, trade, macroeconomic, and sectoral policies. Issues addressed include how to ensure rights to water for the poor in the process of global change; how to harness globalization for improved water use efficiency, environmental policy, water quality, and water-related ecosystems; the role of virtual water for water and food security; and the role of economic incentives for improved livelihoods of the poor under increased trade and liberalization.

2. Investing in agricultural water development and water supply. This covers: the future role/ investment for dams; public vs. private sector roles in water investment; pricing/use rights/institutions for cost recovery; distributional and poverty consequences of alternative cost recovery policies; and optimal investment allocation within agriculture [rainfed versus irrigation, agricultural research versus extension, etc.] and between agriculture and complementary service sectors.

3. Managing transboundary water resources. This may include: the role of alternative institutions in transboundary conflict prevention; the potential for market-oriented approaches in transboundary water sharing; and the integration of agriculture, rural livelihoods, food security and other social concerns into transboundary river basin agreements.

4. Adapting to changes in the global water cycle. Issues addressed include understanding the impact of global/ national, structural changes on the global water cycle; the prevention and mitigation of adverse human effects on global water cycles; understanding the impact of changes in the global water cycle on ecosystem services and human well-being; and the development of adaptation strategies to reduce potentially adverse impacts of global change for the poor.

At present, there are no Theme 5 projects touching on the first research area, "Developing suitable globalization, trade, macroeconomic, and sectoral policies". Perhaps in the future, one or more such projects may be approved and launched. During 2005, the Theme 5 team did organize and conduct a workshop on globalization and trade, which is discussed below.

With regard to the fourth research area, "Adapting to changes in the global water cycle", only one project has been started. It only recently began its activities and for 2005 has little to report. Future synthesis documents will take account of this project's achievements.

While the CPWF focuses research to address water productivity in the context of a basin, global and national policies, institutions and processes, which are the focus of Theme 5, can have significant influence over the ability to improve productivity in a given basin. It is therefore useful to consider these higher-level influences in the context of a basin through a combination of Themes 4 and 5.

The expanded and integrated set combining global/ national with primarily basin issues is as follows:

Increasing the level of water resources available in a basin

- Fostering the safe and productive use of wastewater
- Developing ensembles of small, multi-purpose reservoirs
- Investing in agricultural water development and water supply

Improving governance processes affecting basin-level water allocation

- Enhancing the planning of large dam operations
- Improving groundwater governance
- Fostering better multi-stakeholder governance at multiple scales

- Improving transboundary water policies and institutions

Table 14 shows how this integration unfolds across specific projects.

Developing suitable globalization, trade, macroeconomic, and sectoral policies

Although there are no CPWF projects that focus on this issue, the Theme 5 team made progress by means of workshops and publications.

The Turrialba workshop

During 2005, the Theme 5 team organized a workshop entitled “Globalization and Trade: Implications for Water and Food Security”. It was held at the headquarters of the Tropical Agricultural Research and Higher Education Center (CATIE) in Turrialba, Costa Rica. The objective of the workshop was to identify avenues for policy reform, research gaps and opportunities for collaboration among disciplines. Participants presented research on a wide variety of topics, including legal aspects of trade and investment in the water sector, the impact of globalization on water pollution and transboundary fisheries, trade in virtual water, and possible consequences of climate change.

Table 14: Relevance of CPWF project s to the integrated set of Theme 4/5 issues

Issues for Themes 4 and 5	Projects[18]									
		PN51	PN46	PN48	PN36	PN42	PN40	PN50	PN47	PN53
Globalization, trade, macroeconomic and sectoral policies (no projects at present)										
Increasing the level of water resources available in a basin										
Fostering the safe and productive use of wastewater	100/0	80/0								
Developing ensembles of small, multi-purpose reservoirs			50/10							
Investing in agricultural water development and water supply				20/50				40/40		
Improving governance processes affecting basin-level water allocation										
Enhancing planning of large dam operations					80/0					
Improving groundwater governance						50/35				
Fostering better multi-stakeholder governance at different scales							40/40	40/40		
Improving transboundary water policies and institutions								40/40	40/40	
Adapting to changes in the global water cycle										0/100

[18] Blue = largely assigned to Theme 4; yellow = largely assigned to Theme 5; green = assigned nearly equally to both Themes. The r ation of Theme 4 to Theme 5 assignments is given in the corresponding box.

Experts showed that bilateral, regional, and international trade and investment arrangements impact significantly on developing country water availability and uses. Among international agreements, the WTO (and in particular the GATS and the liberalization of trade in environmental goods) may have very substantial consequences for water use and food security in developing countries. Experts also showed the large effect on water and food in developing countries from non-water sector liberalization (e.g., foreign direct investment agreements in the industrial or agricultural sectors).

Researchers agreed that water privatization has not been a significant source of new funds for investment in water resource development and maintenance and, in general, has not met expectations. Where water issues cross national boundaries, international arbitration tribunals are taking over from national courts in deciding on cases that indirectly impact domestic water and food security.

Despite globalization and international financial flows, there is insufficient investment in water resource and irrigation development. Estimates show that the water sector is in need of US$180 billion annually during 2000-2025, largely for investment in wastewater treatment and irrigation. If raising funds for new irrigation projects is difficult, identifying funding for wastewater disposal and sanitation in developing countries is even more challenging. Financing for the water sector will continue to stem mostly from public sources, but there are opportunities to tap sub-sovereign levels of financing, as is used successfully in the United States. Other important financing sources include revolving funds, pooled funds, and pension funds. Good governance and a separation of political processes from management of the water sector are crucial elements for water supply development to succeed.

With regard to "virtual water" (the water needed to produce a traded product), research was presented showing how trade can help save water. Water-poor countries can reduce irrigation water use when they import food from water-rich countries. But water use would be only six percent higher without virtual water trade. About 20 percent of total cereal trade is thought to be water-related.

Researchers also showed that in the future rainfed production, particularly in Sub-Saharan Africa, can be expected to fail more often than it has in the recent past, a reflection of climate variability and change. Climate change will increase demand for water-controlled, i.e. irrigated, agriculture and may prompt a new review of, and more emphasis on, the roles of both small and large dams for food security.

New book on water rights

The Theme 5 team also has published a book on water rights. Its main conclusions are that water rights can be useful tools for protecting availability of water for basic needs, securing irrigation deliveries, increasing urban water supplies, and enhancing environmental flows. The water rights reforms reviewed in this book show some common patterns in performance problems that induce institutional change, initiative by government, increases in stakeholder consultation, concern with transferability of water rights, and continuing challenges in implementing new policies and responding to environmental needs. As a whole, reform experience suggests that institutional design should pay much more attention to the time dimension of water rights reforms.

Investing in agricultural water development and water supply

When water is scarce, it can make sense to develop new sources of water. This is not always easy (or else water scarcity would rarely be a problem). CPWF projects focus on three ways to increase the amount of available water. Two of these – fostering the safe and productive use of waste water, and developing ensembles of small, multi-purpose reservoirs – were discussed in the context of Theme 4.

Another way of increasing water supplies, of course, is through investment projects involving the construction of dams, irrigation systems, or groundwater development. Tapping water resources by these means, however, is becoming increasingly difficult and expensive. Construction of traditional dams and reservoirs involves enormous environmental and social costs, including the dislocation and resettlement of people. Moreover, the sustainable management and maintenance of existing irrigation systems is undermined by low water prices. This state of affairs threatens effective and equitable water allocation and siphons off financial resources needed for further water resource development. Wise planning of new water projects demands accurate estimates of the costs and benefits of alternative investments in supply and demand management strategies.

CPWF project 48 examines one such investment project – "India's National River-Linking Project (NRLP)". The NRLP program represents multi-purpose investment in water resource development at the largest possible scale. It aims to form a gigantic south Asian water grid which could handle up to 178 billion cubic meters of inter-basin water transfer every year. Project 48 aims to spark a process for providing unbiased and objective assessments of costs and benefits of water development and management interventions such as the NRLP. In the first phase, Project 48 is developing a comprehensive analysis of future scenarios of India's food and water supply and demand (to 2025 in the medium term and 2050 in the longer term).

Managing transboundary water resources

River basins and groundwater aquifers that cross national, state, provincial or regional boundaries present major hurdles to effective water management. In many parts of the world, water is a major source of tension or conflict—between countries, between states or provinces within countries, and between groups of water users with differing interests.

The challenge is to build the institutional capacity and culture of cooperation needed to prevent economic, political or environmental crises before they happen. Research on this issue will examine arrangements for sharing transboundary waters and processes for resolving or avoiding conflicts. A further challenge is to do this in ways that take account of the voice of indigenous, vulnerable populations, and incorporate food and water security concerns in negotiations, and help ensure that the poor are not disadvantaged in situations of overlapping institutions.

CPWF Project 47 is taking an in-depth look at African transboundary water management. It begins by recognizing that there are many international river basins in Africa and that virtually every African country shares at least one of them. Implementation of basin-level integrated water resources management in Africa therefore requires international cooperation among riparian countries. The question, then, is not whether transboundary water management in Africa should be strengthened, but rather how?

Interventions that aim to improve transboundary water management in Africa must take account of two supremely important factors:

> Poverty in Africa is widespread and overcoming poverty often depends on reliable access to water. The poor, however, tend not to be strongly represented in decision-making bodies at the international scale.
>
> Indigenous arrangements in the management of natural resources, in particular land and water, continue to be very important in Africa, a point invariably neglected in international agreements.

The approach taken by project 47 is to develop both "top-down" and "bottom-up" profiles of transboundary governance issues in two case study basins, the Volta and the Limpopo. Local partners have come together into a network that aims to develop recommendations for including indigenous principles into transboundary water management agreements. During 2005, Project 47 researchers and partners began the development of the corresponding basin profiles and case studies. Activities included site

selection, developing preliminary basin institutional profiles, training researchers in data gathering and analysis, pre-testing data collection instruments, data collection, setting up data entry systems, etc. Some preliminary analysis has already been done. Future synthesis documents will summarize some of these findings. Apart from this, Project 47 has created and made public a database of African water laws. It can be accessed at www.africanwaterlaws.com.

A second CPWF project (50) also addresses transboundary water issues, in this case for the Mekong basin. This project was only approved in early 2006, however, and therefore has little to report for 2005.

Projects and themes

Most CPWF projects are assigned to multiple Themes. The projects described in this section have large assignments to Theme 5. With few exceptions, these projects also have large assignments to Theme 4, but not with Themes 1-3. The distribution across Themes of projects with assignment to Theme 5 is shown in Table 15.

Table 15 : Distribution across Themes of project s with a large assignment to Theme 5

Domains and project	*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 sy stem s*	*Theme 5 – The Global food and water system*
Developing suitable globalization, trade, macroeconomic, and sectoral policies (PN 50)					
PN50: Multi-scale Mekong Water Go vernance: Inter-disciplinary research to enhance participatory water governance from local watershed to regional scales	5%	10%	5%	40%	40%
Investing in agricultural water development and water supply (PN 20, 48, 50)					
PN20: Sustaining inclusive Collective Action that Links across Economic and Ecological Scales in upper watersheds (SCALES)		50%		25%	25%
PN48: Strategic analysis of India's pr oposal to link 37 Himala yan and Peninsular rivers	5%	10%	15%	20%	50%
PN50: Multi-scale Mekong Water Go vernance: Inter-disciplinary research to enhance participatory water governance from local watershed to regional scales	5%	10%	5%	40%	40%
Managing transboundary water resources (PN 42, 47, 50)					
PN42: Groundwater governance in Asia: Capacity building through action research in the Indo-Gangetic and Yellow Riv er basins	10%	5%		50%	35%
PN47: T ransboundar y Water Go vernance for A gricultural and Economic Growth and Impr oved Livelihoods in the Limpopo and Volta Basins: Towards African Indigenous Models of Governance [total does not sum to 100%]	10%	10%	5%	40%	40%
PN50: Multi-Scale Mek ong Water Go vernance: Interdisciplinary research to enhance participatory water governance from local watershed to regional scales (M-POWER or Mek ong Program on Water En vironment and Resilience)	5%	10%	5%	40%	40%
Adapting to changes in the global water cycle (PN 53)					
PN53: Food and water security under global change: developing adaptive capacity with a focus on rural Africa	100%				

Beyond Themes – achievements and challenges

Coherence and basins

All CPWF projects work in one or more benchmark basins and focus on issues associated with one or more Themes. In fact, all projects can be placed in a basin by Theme matrix. The above sections have focused on the contributions of projects to Themes. However, the basin side of the matrix is also important. To what extent do approved and funded CPWF projects within a basin contribute to a coherent and systematic effort to improve water productivity and reduce poverty in that basin?

There are at least two reasons why perfect coherence is not be expected. First, there is no benchmark basin in which CPWF projects are solely responsible for conducting research on water, food and poverty. Coherence of effort at the basin level is more likely to be found in a combination of CPWF and non-CPWF projects and activities. Second, CPWF projects were selected through a competitive grant system in which proposal quality was an important factor. When funding is limited, it may not be possible to attain coherence within basins (not to mention balance across basins) while also selecting projects with the strongest proposals.

While keeping these points in mind, a rough assessment of the basin-level coherence of CPWF projects can still be made by looking at the distribution of projects across issues, Themes and basins (Table 16). Several things are immediately apparent.

- Apart from some work on conservation agriculture in project 22, activity in the Andes system of basins is restricted to research on policies and institutions related to water system design, water allocation and governance. There is relatively little work on crop water productivity, aquatic ecosystems, and investment in water resource development.
- In contrast, work in the Yellow River and Karkheh basins is almost entirely focused on crop water productivity (expanded to catchment scale management in project 24), although the number of projects active in these basins is admittedly small.
- In the Nile basin, there is virtually no work on whole-basin integrated water management – something that appears to have major importance in that basin.
- The balance of activity seems somewhat better in the two basins with large areas under irrigated agriculture – the Indus-Ganges and the Mekong basins. Crop water productivity, water management in catchments, aquatic ecosystems, governance and water access, etc., all receive some attention. In addition, several projects are active in both basins.
- Coherence of activity also seems reasonable in the two basins with large areas under drought-prone rainfed systems – the Limpopo and the Volta. There is a striking difference, however, in the technologies and policies being studied in one vs. the other basin – even under seemingly similar environmental conditions.
- Limited CPWF project work is being done in the São Francisco basin, with a single project focused on the role of small reservoirs in increasing water productivity.

Coherence of CPWF work in benchmark basins has recently been strengthened through the introduction of “Basin Focal Projects”. Future synthesis papers will take into consideration the progress and achievements of these BFPs.

Building on past achievements

There are many instances in which CPWF projects build on the accomplishments of earlier non-CPWF research. As long as the earlier research is properly recognized, such a strategy represents a wise use of scarce resources.

Some examples emerge from research on germplasm. Project 2, for example, features multi-location farmer participatory varietal testing of different crops in Eritrea. Farmers test parent lines,

Table 16 : Distribution of CPWF project s across issues,Themes and basins

Issue	Andes	Indus-Ganges	Limpopo	Karkheh	Mekong	Nile	Sao Fco	Volta	Yellow
Theme 1									
Improving crop water productivity in relatively dry rainfed environments			PN1	PN8		PN2		PN5, PN6	PN12
Improving crop water productivity in relatively wet rainfed environments [19]					PN11				
Improving crop water productivity in irrigated and salt-affected areas		PN7, PN10, PN16		PN8	PN7, PN10, PN16	PN7			PN16
Theme 2									
Increasing farm-level water productivity in catchments through technical change		PN17	PN24	PN11					
Increasing water productivity in catchments through multiple-use systems	PN28	PN28	PN28		PN28				
Reallocating water resources in catchments towards high productivity uses	PN40		PN30		PN25			PN40	
Fostering the adoption of water-efficient practices in catchments	PN20, PN22					PN20			
Theme 3									
Managing wetlands in dry environments			PN30						
Managing fisheries in tropical reservoirs		PN34				PN34		PN34	
Managing fisheries in irrigated fields, floodplains and deltaic lowlands		PN35			PN35				
Managing the saline – freshwater interface in coastal areas		PN10			PN10				
Fisheries management across scales					PN52				

Themes 4 and 5									
Generating basin-level benefits from farm-level interventions			PN17, PN30			PN37		PN5	
Increasing the level of water resources available in a basin									
❑Fostering the safe and productive use of wastewater								PN38, PN51	
❑Developing ensembles of small, multipurpose reservoirs			PN46				PN46	PN46	
❑ Investing in agricultural water development and water supply		PN48							
Improving governance processes affecting basin-level water allocation									
❑ Enhancing planning of large dam operations						PN36			
❑Improving groundwater governance		PN42							PN42
❑Fostering better multi-stakeholder governance at different scales	PN40							PN40	
❑Improving transboundary water policies and institutions			PN47		PN50			PN47	
Adapting to changes in the global water cycle						PN53			

[19] Another project, PN15, also works on this issue. At present, however , its activities lie outside of the currently defined bench mark basins.

segregating populations and breeding lines of barley, wheat, chickpea, lentil and other crops with respect to attributes identified by farmers and end-users. This work clearly builds on prior investments in crop improvement.

A similar argument may be made for the project 16, focused on the development of aerobic rice germplasm for water-scarce rice production areas in China, the Philippines, Laos and northeast Thailand, and India. Already, suitable aerobic rice varieties have been identified for northern China and for the Philippines. This rapid progress has only been possible because PN16 builds on earlier crop improvement research by IRRI and collaborating NARES.

Examples of CPWF projects building on earlier non-CPWF research may also be found in the area of on-farm water management. Projects 5, working on the Volta basin, emphasizes research on water harvesting (tied ridges, half moons, zaï and other planting pit technologies) and soil fertility management (organic amendments, fertilizer micro-dosing – the very precise application of very small amounts of inorganic fertilizer). Most of these practices are well-known in the target countries and some (e.g., the zaï) already have been adopted by large numbers of farmers. project 5 adds value, however, by examining the downside risk of technology by means of DSSAT modeling.

Many Theme 2 projects, e.g., on multiple-use systems, collective action, payment for environmental services, e.g., follow on a substantial amount of recent research on these same topics. In some instances, the role of the CPWF project is simply to scale out practices that have been proven to be widely successful. Further examples can be cited for Themes 3-5.

By building on past success, the CPWF can greatly increase the efficiency with which it uses its limited resources. In such cases, however, care should be taken to accurately and transparently recognize the importance of these earlier successes.

Capacity-building

The CPWF is not restricted to research; it also has a capacity-building goal, which is to “Increase the ability of scientists to carry out integrated research on water and food with a basin perspective”.

CPWF focuses on building the capacity of individuals, specifically researchers, as learners, appliers and promoters of integrated scientific approaches to evaluating and enhancing water productivity for food production, livelihood generation, and ecosystem services. For doing so, four mechanisms are under development: “Interdisciplinary post-graduate cohorts”, “Bridging programs”, “Internships”, and “Advanced training opportunities”. These mechanisms are further described in other CPWF materials.

Tables 17 and 18 provide information on the scale of CPWF capacity-building activity in Themes 2 and 4.

Table 17: Capacity building activities as of December 2005, Theme 2

	Training of BA students	Training of MA/MSc students	PhD students	Post Doctoral fellows
PN 15	2	2	2	
PN 17	6	25	5	
PN 20	96	UF MSc Students	2	3
PN 24				
PN 28		1	2	1
PN 30	4	1		
PN 37				
PN 40		2	3	1
PN 46	4	3		

Table 18: Capacity building by project and region, Theme 4

	Number to be trained		
Brief Title	Africa	Asia	South America
PN05 - Rainwater and Nutrient Use Efficiency	12		
PN17 - IWRM for Improved Rural Livelihoods	22		
PN23 - Resources Management for Sustainable Livelihood		10	
PN25 - Companion Modeling & Water Dynamics		6	
PN30 – Wetlands, Social welfare and Environmental Security	6		
PN36 – Improved livelihoods through dam management	8		
PN37 - Nile Basin Livestock Water Productivity	18		
PN38 - Safer (peri) Urban Vegetable Productivity	25		
PN40 - Integrating Governance and Modeling	8		7
PN42 - Groundwater Governance in IGB & YRB		80	
PN46 - Small Multi-Purpose Reservoir Ensemble Planning	14		6
PN47 - African Models of Transboundary Governance	18		
PN50 - Enhancing Multi-Scale Mekong Water Governance		7	
PN51 - Waste water irrigation - opportunities and risks	6		

Source: CPWF. 2006. Theme 4: Crop Water Productivity Improvement 2005 Synthesis Report

Major achievements – vision, design, and implementation

The CGIAR Challenge Program on Water and Food (CPWF) is charged with a supremely important but enormously difficult task. Through increased water productivity, it seeks to help improve food security, reduce poverty and protect the environment, in a world of growing water scarcity and increased competition for water resources. Water scarcity is driven by broad and irresistible processes of population growth, urbanization, and globalization. These processes, when combined with the elimination of wetlands and the degradation of land and water resources, undermine the world's capacity to feed a larger and wealthier population while also maintaining the environmental and ecological services derived from water resources.

In such a world, the Challenge Program specifically works toward poverty alleviation through increased sustainable livelihoods; food security for the poor; improved health through better nutrition, lower agriculture–related pollution and reduced water-related disease; and environmental security through the preservation of water-related ecosystems and their associated biodiversity.

The CPWF is most concerned with the large numbers of the very poor in developing countries. In these countries, 70-90% of water is consumed in agricultural production. Water is also needed, however, for rural and urban domestic use, industrial use, power generation, river transport, fish production, and the preservation of wildlife habitat and ecological processes. Despite rapid urbanization, the rural population in the poorest countries will continue to increase, and put additional pressure on the natural resource base. One way to meet these competing needs is to increase water productivity, especially in agriculture. More food must be produced using less water.

Such problems are not quickly solved and the CPWF itself is relatively young. During its brief history, then, what have been its major achievements? The CP has achieved success in four distinct areas: vision and design, program implementation, and on-the-ground impacts.

Vision and design

The vision of the CPWF is an ambitious one of partnership-based research for development that generates favorable impacts at the largest possible scale. It does this by:

- Focusing on some of the developing world's largest and most important river basins (e.g., Indus-Ganges, Mekong, Nile, Yellow)
- Studying these basins at all scales of analysis (plant, field, agroecosystem, catchment, sub-basin, whole basin, national, global)
- Taking account of all landtypes found in these basins (upper catchments, dryland and humid rainfed agricultural areas, irrigated agricultural areas, urban areas, coastal areas, inland and coastal fisheries, environmentally-sensitive areas)
- Incorporating a wide range of tools and approaches (plant breeding, crop management, landscape and agroecosystem management, trade-off analysis, institutional analysis, stronger governance and decision-support in water resource allocation and investment., scenario analysis)
- Identifying highly innovative topics for research (e.g., livestock water productivity, aerobic rice systems, payments for environmental services, the downstream consequences of upstream interventions, integrated strategies for dryland areas combining drought-tolerant varieties and rainwater harvesting practices).

Program implementation

As befits a CGIAR Challenge Program, the CPWF has welcomed a wide range of stakeholders and partners in accord with their ability to help achieve Program goals. Decisions on research investments (project selection) have been based on a competitive grants process in which proposal quality was evaluated by an independent external panel. The usual weakness of a competitive grants approach – lack of coherence in the research agenda – has been addressed through Basin Focal Projects and synthesis research.

Major achievements – technologies, policies, and information

It is all very well to have a broad compelling vision, an innovative research agenda, and transparent program implementation – but what has been achieved on the ground?

In describing on-the-ground impacts, it is important to keep a sense of perspective. This synthesis describes CPWF progress through the end of 2005 – but of all the projects described in the above sections, only 18 were approved and funded before January 1, 2005. The following discussion largely focuses on those 18 projects.

CPWF project achievements include progress in the development of technologies, policies and information.[20] Some relate specifically to irrigated, high-rainfall, or dryland environments. Others have relevance across environments.

Irrigated environments

Major achievements for irrigated environments include:

Progress in the development of aerobic rice germplasm and accompanying management practices, to produce more rice while using far less water than required with puddling.

Advances in the development of salt-tolerant germplasm for rice, wheat, barley and mustard, to make more effective use of salt-affected irrigated areas. Specific advances have been made in the mapping of QTLs for salinity tolerance in rice.

Progress in formulating strategies for dealing with seawater incursion into rivers, including:

- Water management technologies that reduce or eliminate the harm done to crops by saltwater intrusion.
- Technologies that transform saltwater intrusion from a problem into an opportunity (e.g., the introduction of rice-fish and shrimp poly-culture).
- The development or improvement of simulation models to underpin decision-support systems for water allocation and use in the context of conflicting stakeholder needs in complex coastal environments.

Investments in the construction of community-level dugouts or reservoirs to store water for small irrigation and fish production, and house-hold water storage reservoirs to allow farm families to more readily engage in income-related crop and food processing.

An improved understanding of how to use wastewater in irrigated peri-urban vegetable production, in ways that result in products that are safe and nutritious for consumers.

High-rainfall environments

Major achievements for high-rainfall environments include:

Progress in understanding and further developing "slash and mulch" practices for hillside agroecosystems, and targeting their dissemination as a replacement for "slash and burn" practices.

Advances in the development of conservation agriculture practices, and accompanying farm implements, for direct sowing into crop residues without tillage. This is accompanied by a better understanding of the consequences of these practices for erosion control and downstream water quality.[2]

Dryland environments

Major achievements for dryland environments include:

Progress in the development and dissemination (through participatory varietal selection and seed production schemes) of drought-tolerant varieties of sorghum, barley, wheat, chickpea, lentil, faba bean, and cowpea.

[20] In this section, detailed descriptions of 2005 project activities are not provided (e.g., inception workshops, training events, then establishment of networks, literature reviews, the formulation of conceptual frameworks, rapid appraisals, site selection, site characterization, researcher or farmer-managed experiments, spatial analysis, simulation model development, investment analysis, institutional analysis, etc.) Such details may be found in individual project progress reports.

Improved understanding (through GIS/ agroecological zoning) of target areas for the dissemination of drought-tolerant varieties and production of breeder seed.

Advances in understanding livelihood vulnerability and resilience, and farmer's innovations, in dry areas.

Important steps towards a conceptual framework for understanding and improving livestock water productivity.

Progress in tailoring combinations of water harvesting systems and fertilizer micro-dosing to specific dryland locations, and in understanding the performance and associated risk of these practices.

Advances in understanding and managing ensembles of small reservoirs in dry areas. This includes a better understanding of how changes in the management of an upstream reservoir can impact water availability in downstream reservoirs.

Steps forward in formulating guidelines for the utilization of scarce wetlands in dry environments. This involves the development of simulation models for use in analyzing trade-offs among alternative mixtures of agricultural (crop and livestock) and fisheries water-use strategies in wetlands.

Across environments

Progress in the global dissemination of multiple-use water systems, through Learning Alliances.

Steps forward in learning how to strengthen multi-stakeholder governance structures by identifying problems, shaping policy options, and establishing criteria for their evaluation by stakeholders, where stakeholder evaluation of options is assisted by a simulation model capable of predicting agent-agent and agent-environment interactions.

An improved understanding of indigenous water use institutions and regulations in Africa, culminating in the publishing of a database of African water laws. This is done with an eye to identifying indigenous approaches to transboundary water governance.

A deeper understanding of how collective action can be used by people living in catchments can help them escape from poverty. Basic to this is an improved understanding of the dynamic biophysical, social and political interactions that take place across different watershed scales.

Advances (through a CPWF-organized workshop) in understanding the implications of globalization and trade on water and food security, including:

- The likely effects on water use and food security in developing countries of the WTO (and in particular the GATS and the liberalization of trade in environmental goods)
- The large effect on water and food in developing countries from non-water sector liberalization (e.g., foreign direct investment agreements in the industrial or agricultural sectors).

Challenges and opportunities

Discussion in previous sections has identified several opportunities where it may be possible for the CPWF to improve coherence, increase research efficiency, and accelerate progress towards achieving its development goals. Here are some of them:

Encouraging cross-project learning on ways to improve crop water productivity in relatively dry rainfed environments. Several projects have a focus on the improvement of crop water productivity in relatively dry rainfed environments. Some are restricted to germplasm development and dissemination. Others focus on the development and introduction of new crop, soil, water or nutrient management practices (but with a large divergence in the selection of technologies for testing). Still others try to follow an integrated approach, combining improvements in germplasm; crop, soil, water or nutrient management practices; and land and agroecosystem management. It may be useful to explore the reasons for this dissimilarity in the selection of interventions and to identify opportunities for mutual learning among projects working in these environments.

Harnessing lessons learned on improving crop water productivity in relatively wet rainfed environments. Only two projects, 11 and 15, conduct research on improving crop water productivity in relatively wet rainfed environments (rainfed rice-based systems and slash and mulch hillside systems, respectively). Because the number of projects is so limited, while the potential area of application is so large, it may be useful to conduct site similarity analysis to identify

larger areas in benchmark basins where the lessons learned in these two projects may have relevance.

Taking a broader approach to the development of aerobic rice systems. Project 16 describes good progress made to date in the development of germplasm for aerobic rice systems. Very widespread adoption of these systems may hold the potential for substantial improvements in crop water productivity, and possibly basin level water productivity, in irrigated areas. But the key to the widespread use of such germplasm may lie in the development of complementary land and water management systems, e.g., bed and furrow systems with effective weed management for rice and following crops. Basin coordinators and BFP managers, as well as project 16 staff, may wish to further explore this possibility.

Strengthening agroecological zoning and site similarity analysis for scaling out. In Theme 1 and 2 projects, there is occasional use of agroecological zoning to guide scaling out of new technologies (even though most projects recognize the importance of supporting policies and institutions in fostering farmer adoption of suitable new practices). Even the best farm-level technologies contribute little to achieving development goals if they are not taken up by large numbers of farm families over large areas. Basin Focal Projects are designed to have a strong GIS capacity, which can be applied to technology targeting as well as to water poverty and water productivity mapping. BFPs and first-call projects might wish to work together on applying spatial analysis for scaling out.

Fostering closer links between research on salt-affected areas and on groundwater governance. Several projects seek to address problems of salt-affected areas in irrigated agriculture. Project 7 emphasizes germplasm development for salt tolerance while PN8 seeks germplasm and land management technologies to improve water productivity and reduce water-logging and salt build-up (in the Karkheh basin). There is another project, however, with potentially great relevance to salt problems – Project 42, focusing on groundwater governance. There are many places where salt problems are linked to groundwater quality and groundwater use practices. Policies and institutions governing groundwater use may be an essential part of integrated efforts to address productivity-reducing salinity and sodicity problems.

Developing a cross-basin community of practice on water resource governance and decision-support. Related to the above, those projects in Themes 2, 4 and 5 that focus on processes for improving governance and decision-support in water management, e.g., projects 25, 30, 40, 42, 47, 50, might wish to form a community of practice for mutual learning and information exchange. In this way, cross-basin learning can also be encouraged.

Examining the basin-level consequences of farm-level interventions in irrigated areas. There are numerous CPWF projects focusing on technology development to improve farm-level crop water productivity, whether in catchments, dry or wet rainfed areas, or irrigated areas. These are rarely accompanied, however, by related activities to anticipate the basin-level consequences for poverty and water productivity that may emerge from widespread adoption of these technologies. The few existing examples all concentrate on dryland areas in Africa, where the downstream consequences of upstream interventions are likely to be relatively small. It may be appropriate to encourage more work on downstream consequences of upstream interventions in irrigated areas. The Basin Focal Projects and Theme 2 work on this – but existing projects should probably help out.

Conduct ex-ante analysis on the anticipated pay-offs from different kinds of investments in different Themes and basins . By bringing together technology, policies and institutions in an integrated framework, many CPWF projects make it clear that they mean business – they will settle for nothing less than substantial favorable impacts on water productivity, food security, and poverty at the farm, catchment, and river basin levels. Even if all projects were to result in anticipated levels of adoption, however, the numbers and kinds of people benefiting, the magnitude of benefits per person, the time frame of adoption – and how these unfold at different levels of analysis – all affect returns on research investment. At some point, it may be useful for the CPWF coordination unit or one or more BFPs to look into this, as a possible guide to future CPWF research priorities.

Final words

The CPWF must necessarily find it challenging to provide thorough and systematic reports of its activities and achievements. This is because its work is distributed across 33 distinct projects, covering nine benchmark basins, and guided by five distinct Themes. The easy way out would be to merely publish separate project, basin and Theme reports, regardless of possible inconsistencies or overlaps. But such an approach might also fail to identify exciting opportunities for future progress and impact.

Our hope is that this synthesis report contributes to a bringing together of information, ideas, and actions in ways that stimulate even more rapid progress of the CPWF towards achieving its very ambitious goals.

Annex 1: Index of project numbers, names, basins and themes

Project Number	Project name	Basins	Discussed in the context of:
PN1	Increased Food Security and Income in the Limpopo Basin through Integrated Crop, Water and Soil Fertility Options and Public-Private Partnerships	Limpopo	Theme 1
PN2	Improving Water Productivity of Cereals and Food Legumes in the Atbara River Basin of Eritrea	Nile	Theme 1
PN5	Enhancing Rainwater and Nutrient Use Efficiency for Improved Crop Productivity, Farm Income and Rural Livelihoods in the Volta Basin	Volta	Themes 1 and 4
PN6	Empowering Farming Communities in Northern Ghana with Strategic Innovations and Productive Resources in Dryland Farming	Volta	Theme 1
PN7	Development of Technologies to Harness the Productivity Potential of Salt-Affected Areas of the Indo-Gangetic, Mekong, and Nile River Basins	Indus-Ganges, Mekong, Nile	Theme 1
PN8	Improving On-farm Agricultural Water Productivity in the Karkheh River Basin	Karkheh	Theme 1
PN10	Managing Water and Land Resources for Sustainable Livelihoods at the Interface between Fresh and Saline Water Environments in Vietnam and Bangladesh	Indus-Ganges, Mekong	Themes 1 and 3
PN11	Rice Landscape Management for Raising Water Productivity, Conserving Resources and Improving Livelihoods in Upper Catchments of the Mekong and Red River Basins	Mekong	Themes 1 and 2
PN12	Conservation Agriculture for the Dryland Areas of the Yellow River Basin: Increasing the Productivity, Sustainability, Equity and Water Use Efficiency of Dryland Agriculture, while Protecting Downstream Water Users	Yellow	Theme 1
PN15	Quesungual Slash-and-Mulch Agroforestry System (QSMAS): Improving Crop Water Productivity, Food Security and Resource Quality in the Sub-humid Tropics	(outside of bench-mark basin frame -work)	Theme 1
PN16	Developing a System of Temperate and Tropical Aerobic Rice (STAR) in Asia	Indus-Ganges, Mekong, Yellow	Theme 1
PN17	The Challenge of Integrated Water Resource Management for Improved Rural Livelihoods: Managing Risk, Mitigating Drought and Improving Water Productivity in the Water-Scarce Limpopo Basin	Limpopo	Themes 1, 2 and 4
PN20	Sustaining Inclusive Collective Action That Links across Economic and Ecological Scales in Upper Watersheds (SCALES)	Andes, Nile	Themes 2 and 5

PN22	Payment for Environmental Services as a Mechanism for Promoting Rural Development in the Upper Watersheds of the Tropics	Andes, Nile	Theme 2
PN23	Linking Community-Based Water and Forest Management for Sustainable Livelihoods of the Poor in Fragile Upper Catchments of the Indo-Gangetic Basin	Indus-Ganges	
PN24	Strengthening Livelihood Resilience in Upper Catchments of Dry Areas by Integrated Natural Resources Management	Karkheh	Theme 2
PN25	Companion Modeling for Resilient Water Management: Stakeholder's Perceptions of Water Dynamics and Collective Learning at the Catchment Scale	Mekong	Theme 2
PN28	Models for Implementing Multiple-Use Water Supply Systems for Enhanced Land and Water Productivity, Rural Livelihoods and Gender Equity	Andes, Indus-Ganges, Limpopo, Mekong, Nile	Themes 2 and 4
PN30	Wetlands-Based Livelihoods in the Limpopo Basin: Balancing Social Welfare and Environmental Security	Limpopo	Themes 2, 3 and 4
PN34	Improved Fisheries Productivity and Management in Tropical Reservoirs	Indus-Ganges, Nile, Volta	Theme 3
PN35	Community-Based Fish Culture in Irrigation Systems and Seasonal Floodplains	Indus-Ganges, Mekong	Theme 3
PN36	Improved Planning of Large Dam Operation: Using Decision Support Systems to Optimize Livelihood Benefits, Safeguard Health and Protect the Environment	Nile	Theme 4
PN37	Increasing Water-Use Efficiency for Food Production through Better Livestock Management - The Nile River Basin	Nile	Theme 4
PN38	Safeguarding Public Health Concerns, Livelihoods and Productivity in Wastewater Irrigated Urban and Peri-Urban Vegetable Farming in Ghana	Volta	Theme 4
PN40	Integrating Knowledge from Computational Modeling with Multi-Stakeholder Governance: Towards More Secure Livelihoods through Improved Tools for Integrated River Basin Management	Andes, Volta	Themes 2 and 4
PN42	Groundwater Governance in Asia: Capacity Building through Action Research in Indo-Gangetic (IGB) and Yellow River (YRB) Basins	Indus-Ganges, Yellow	Themes 4 and 5
PN46	Planning and Evaluating Ensembles of Small, Multi-purpose Reservoirs for the Improvement of Smallholder Livelihoods and Food Security: Tools and Procedures	Limpopo, Sao Francisco, Volta	Theme 4
PN47	Transboundary Water Governance for Agricultural and Economic Growth and Improved Livelihoods in the Limpopo and Volta Basins: Towards African Indigenous Models of Governance	Limpopo, Volta	Themes 4 and 5
PN48	Strategic Analysis of India's National River-Linking Project (NRLP)	Indus-Ganges	Theme 5

PN50	Multi-scale Mekong Water Governance: Inter-disciplinary Research to Enhance Participatory Water Governance from Local Watershed to Regional Scales	Mekong	Themes 4 and 5
PN51	The impact of waste water irrigation on human health and food safety among urban communities in the Volta Basin – opportunities and risks	Volta	Theme 4
PN52	Strengthening Fisheries Management Institutions in the Lower Mekong River Basin through Collaborative Research and Data Synthesis across Multiple Scales	Mekong	Theme 3
PN53	Food and water security under global change: developing adaptive capacity with a focus on rural Africa	Nile, Limpopo	Theme 5

Annex 2: List of acronyms and abbreviations

ACIAR Australian Council for International Agricultural Research

CATIE Tropical Agricultural Research and Higher Education Center

CGIAR Consultative Group on International Agricultural Research

COP Community of practice

CPWF Challenge Program on Water and Food

DSSAT Decision Support System for Agro technology Transfer

FAO Food and Agriculture Organization

GATS General Agreement on Trade in Services

GIS Geographic information system

GPS Global positioning system

INRM Integrated natural resource management

IWMI International water management institute

IWRM Integrated water resource management

LA Learning alliance

MUS Multiple-use systems

NARES National agricultural research and extension systems

NGO Non-governmental organization

NRLP National River-Linking Project

QSMAS Quesungual slash-and-mulch agroforestry system

QTL Quantitative trait loci

RWS Relative water supply

STAR System of temperate and tropical aerobic rice

WEAP Water Evaluation and Planning

WHO World Health Organization

WHS Water harvesting systems

WTO World Trade Organization

CGIAR Challenge Program on
WATER & FOOD

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