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CGIAR Challenge Program on Water and Food

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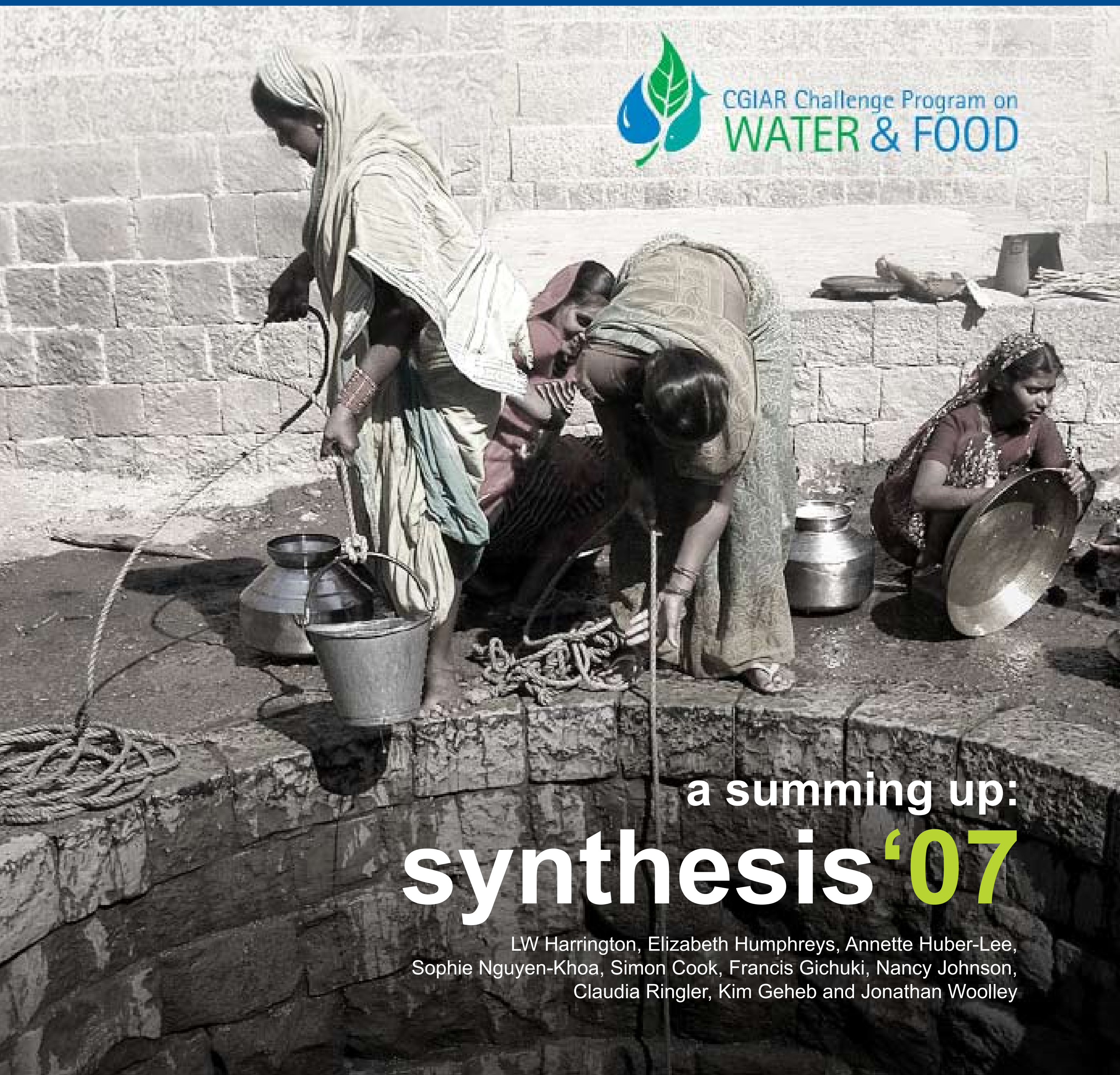

a summing up: synthesis '07

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CGIAR Challenge Program on
WATER & FOOD

The Challenge Program on Water and Food (CPWF), an initiative of the Consultative Group on International Agricultural Research (CGIAR), contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase water productivity for agriculture—that is, to change the way water is managed and used to meet international food security and poverty eradication goals—in order to leave more water for other users and the environment.

The CGIAR Challenge Program for Water and Food's Annual Synthesis Reports capture the process of producing 1) new insights, by combining findings from different research outputs, and 2) integrated knowledge on various aspects of a research issue.

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

Executive summary

This reports summarizes and synthesizes activities and achievements of the CGIAR Challenge Program on Water and Food (CPWF) through the end of 2007.

The CPWF is an intiative of the CGIAR designed to take on the global challenge of water scarcity and food security. It is an international, multi-institutional research-for-development initiative that brings together scientists, development specialists and river basin communities, and seeks to create and disseminate international public goods (IPGs) helpful in achieving food security, reducing poverty, improving livelihoods, reducing agriculture–related pollution, and enhancing environmental security.

The CPWF conducts its research on water and food in nine 'benchmark' river basins, organized around five different themes. This work is being implemented through competitive-call projects, Basin Focal Projects (BFPs), small grant projects and synthesis research. This report is one example of the latter.

PROJECTS AND OUTPUTS

Part of the CPWF's work has focused on increasing water productivity in rainfed environments. Achievements include the further development of conservation agriculture for no-till sowing into crop residues; "slash and mulch" to replace "slash and burn" practices in hillside agriculture; water harvesting systems for dryland locations; understanding livelihood vulnerability and farmers' coping strategies; and developing and encouraging the distribution—through community 'participatory' varietal selection and seed schemes—of drought-tolerant sorghum, wheat, and other crops.

Progress has also been made in increasing water productivity in irrigated and salt-affected environments, especially where water is scarce and there are opportunities to increase its productivity. Examples include the development and testing of salt-tolerant germplasm for rice and other crops to make more effective use of salt-affected areas; understanding how to use wastewater in irrigated peri-urban agriculture to produce safe and nutritious vegetables; and developing aerobic rice germplasm and management practices to produce more rice with less water.

Some CPWF projects have focused on developing ways to foster multi-stakeholder dialogue and negotiation. Examples include advances in understanding how to apply 'payment for environmental services' (PES) so that downstream water users may influence upstream water management; progress in fostering an increased

appreciation for multiple-use water systems (MUS); strategies for dealing with seawater incursion into rivers; improvements in the understanding of indigenous water use institutions in Africa to identify new approaches to transboundary water governance; improvements in managing small reservoirs in dry areas, and; advances in strengthening multi-stakeholder governance structures through identifying problems, shaping policy options and enabling stakeholder evaluation of options via simulation models.

In the area of integrated river basin management, ways have been found to introduce livestock into the water productivity equation, while capacity-building is being used as means of addressing seemingly intractable problems of groundwater governance. Basin Focal Projects have made progress in understanding the inter-relationships between water availability, water productivity and poverty, and the dramatic consequences of water management in one location on water availability downstream.

Policy research has been conducted on global and national issues, such as globalization, climate change and trade. This includes research on water rights reform and the use of multi-stakeholder platforms to ensure rights for the poor under global change processes. Further examples of research on policy issues include work on incentives, investment and financing of agricultural water development; transboundary water policy and institutions; and adapting to changes in the global water cycle.

The BFPs, focusing on river basins rather than Program Themes, have worked to develop whole-basin assessments of water availability, poverty, food security, and water productivity; to identify water-related institutional and technical interventions, and; to ascertain the extent to which the use of these interventions might contribute to poverty reduction, livelihoods resilience, and environmental conservation. In performing these functions, they have sought to take account of how upstream interventions may affect downstream water uses and users. BFPs have had only tenuous links with other projects.

CHALLENGES AND OPPORTUNITIES

This report suggests a number of areas where CPWF projects and BFPs could further integrate and strengthen their work. These include:

- Building more systematically on what is known: for some research questions in some basins, a body of experience already exists, which could serve as a foundation for further advances by the CPWF
- Fostering greater sharing of information and experience across projects working on similar issues in similar environments
- Paying more attention to ‘scaling out and scaling up’ of technical and institutional innovations studied at the farm or community level
- Designing institutional innovations that are sustainable
- Developing and systematically applying methods for understanding and managing downstream and cross-scale consequences of research innovations
- Encouraging improved integration across Themes as well as between Themes and Basin Focal Projects
- Understanding how the global or national policy context may pre-determine the extent to which farm- or community-level level technical or institutional innovations can be widely adopted
- Confronting the question, “To what extent does success in improving crop water productivity truly help solve problems of poverty and food insecurity?”

Contents

Contents

Foreword

Synthesis is a process of combining separate elements, thoughts, ideas, or information to form a coherent whole. CPWF synthesis research seeks to help make sense of the large body of dispersed data and information that accumulates over time. 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.

In 2004, the inaugural CPWF synthesis report introduced the CPWF benchmark basins, the overall research approach, and the research agenda for each basin as determined through diagnostic research and stakeholder consultation. The 2005 report analyzed and described the conceptual frameworks adopted by the five CPWF research Themes; the goals, objectives, and research questions for each Theme; the subject matter addressed by different competitive grant projects; the distribution of projects across Themes and benchmark basins; and Challenge Program agenda coherence.

The 2006 synthesis report featured a theme-by-theme discussion of competitive grant projects and their progress. In addition it briefly discussed Basin Focal Projects (BFPs), capacity-building and selected non-project activities. Where the 2005 report emphasized the distribution of projects across themes and basins, and implications for Program balance and coherence, the 2006 report called attention to opportunities for closer integration across themes, across basins, and between themes and BFPs.

Opportunities were identified in the areas of innovation systems and scaling out; understanding and managing downstream and cross-scale consequences of innovation; the sustainability of institutional innovations; and the effectiveness of water-related interventions to address questions of poverty and food security. The 2006 report was circulated as a CPWF internal document only.

Synthesis '07 updates the findings of the 2006 report, but it also taps the rapidly growing body of research outputs and achievements from competitive grant projects and BFPs, and continues to explore opportunities to better integrate research and harness research outputs for development outcomes.

Given the large volume of new research results that recently have become available, it has not been possible to give updates for each and every project: this 2007 update is necessarily incomplete. Instead, emphasis has been placed on projects with particularly rapid progress, or that exemplify opportunities to increase the coherence and integration of the CPWF research agenda.

Most of the suggestions made in the 2006 report regarding opportunities for closer integration across Program Themes, across basins, and between Themes and BFPs remained valid through the end of 2007. They have been subsequently accounted for in planning for the CPWF's Phase 2.

Liz Humphreys (Theme Leader T1) provided an abundance of new material on Theme 1 projects, as did Francis Gichuki (former Theme Leader T4) for Theme 4. Sophie Nguyen-Khoa (Theme Leader T3) drafted new material on Theme 3 projects. Updates for Themes 2 and 5 were drawn from selected project reports. Simon Cook assisted with the expanded section on BFPs and their outputs.

Unless otherwise specified, the information in this synthesis paper is drawn from CPWF competitive grant project and BFP reports, draft synthesis papers developed by Theme Leaders, and the CPWF Medium-Term Plan for 2006-08.

Larry Harrington
on behalf of the Science Leaders of the CGIAR Challenge Program on Water and Food

Introduction

The CGIAR Challenge Program on Water and Food

Several years ago, an International Forum on Water and Food was held in Vientiane, Laos. Its conclusions were summarized in what has come to be known as the 'Vientiane Statement'. This statement describes water-related problems at the global level and what can be done about them through research, development, investment, and policy change. Ending with a call to action, the Statement begins as follows:

"We recognize the huge global problems posed by hunger, poverty, and disease . . . We recognize the many obstacles to overcoming these problems, among them climate change, resource degradation, and impaired ecosystems. We perceive, however, the presence of a further issue of paramount importance, one that must be addressed if the Millennium Development Goals are to be achieved: the rapidly unfolding and unprecedented crisis of global water scarcity . . . Growing and urbanizing populations will need more water for household consumption, power generation, and industrial production – and for increased food production and the provision of important ecological services. Over the next 20 years, food production must increase by over 30%, much of it in poor, water scarce developing countries. This must be achieved without excessive damage to ecosystems . . . We seek a more water and food secure world, one where wise water management, innovative technologies and effective institutional arrangements work together towards eliminating hunger, poverty and disease, and where ecological services and resource quality are preserved. Such a world is within our reach." (See Annex 3)

For the past several years, the CGIAR Challenge Program on Water and Food (CPWF) planned and carried out an aggressive and innovative program of research on the very issues raised by the Vientiane Statement. The purpose of this report is to summarize and synthesize activities and achievements of the CPWF through the end of 2007.

The CGIAR's four Challenge Programs are defined as time-bound, independently-governed programs of high-impact research that target CGIAR goals in relation to complex issues of overwhelming global and/or regional significance. These goals require partnerships among a wide range of institutions in order to deliver real world impact.

As one example of a Challenge Program, the CPWF is often described as an international, multi-institutional research-for-development initiative that brings together scientists, development specialists, and river basin communities, and seeks to create and disseminate international public goods helpful in achieving food security, reducing poverty, improving livelihoods, reducing agriculture-related pollution, and enhancing environmental security. It was designed as a three-phase, 15-year endeavor. Several years have passed since the start of Phase 1 (2003-2008) which began with an inception phase in 2003 and was followed by full CP launch in January 2004. Initial planning for a second phase began in early 2007.

Research Activities

CPWF conducts research on water and food in nine benchmark basins, organized around five Themes. This research is executed through competitive 'first call' projects, Basin Focal Projects, small grant projects and synthesis research.

First call projects: Most CPWF research is implemented through projects that were selected through a competitive grant process. CPWF's first call for proposals yielded a portfolio of 50 high quality projects, of which more than 30 received funding. Most of this report will focus on the activities and achievements of these projects. A second call for competitive grant proposal concept notes was announced during 2006, with a corresponding call for full proposals in 2007. Field activities for approved projects began in 2008 and are not discussed in this summary.

Small grant projects: The 14 small grant projects—whose total cost is equivalent to less than one average first call project—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 a wider scale. Accounts of their activities and outputs have not been incorporated into this synthesis document.

Basin Focal Projects: BFPs add value to Program research by marshaling and making available knowledge, for specific benchmark basins, on water availability and access, water productivity, water poverty, the policy and institutional context within which water-related investments are made, and opportunities for water-related interventions that help meet Program and partner developmental goals. The design, plans, activities and accomplishments of BFPs through 2007 are summarized in a separate section.

Synthesis: The CPWF deals with complex and dynamic 'systems' for which a growing number of stakeholders are generating information. Synthesis research is needed to make sense of the large body of research findings that accumulate over time.

WATER PRODUCTIVITY

Water productivity is a fundamental concept in the CPWF and is used in one way or another by most projects, themes and basins. 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. It is the amount of water made unavailable for reuse, through evaporation, contamination or flow to a saline sink.

BENCHMARK BASINS

The CPWF believes that research on water and food is best conducted in the context of a defined river basin. How water is managed within a basin can affect agricultural productivity and sustainability, livelihoods, income distribution, and the provision of ecosystem services. The CPWF uses each benchmark river basin as a basic unit of analysis. The benchmark basins are the Indus-Ganges, Karkheh, Limpopo, Mekong, Nile, São Francisco, Volta and Yellow river basins, and the Andes system of basins.

Some of them, such as the Volta or the Limpopo, combine intense poverty with water scarcity in areas dominated by rainfed agriculture. Others, such as the Indus-Ganges, feature large populations of poor people that are increasingly affected by water and land degradation in both irrigated and rainfed areas. Together, the nine basins represent most of the water and food challenges of developing countries.

THEMES

CPWF themes are a means for addressing different aspects of the water and food challenge and serve to package information at different scales. Each theme is led by a specialist from a different CGIAR center. In this synthesis, activities and accomplishments are discussed separately for each theme. Each thematic discussion concludes with a final section on “reflections and observations”. These are intended to draw attention to opportunities for improving CPWF efficiency and effectiveness through stronger cross-theme integration.

The five themes are:

Theme 1: Crop water productivity improvement

Theme 1 seeks to improve crop water productivity by addressing problems of abiotic stress, such as drought, salinity, and nutrient deficiencies. Means for achieving this include crop genetic improvement for stress tolerance, crop and agroecosystem management, landscape management, and innovative institutions and supporting policies. The challenge confronting Theme 1 is rather broader than might appear on the surface. It is not merely to develop technologies that improve crop water productivity – but rather, to do so in ways that increase food security, reduce poverty, and improve the resilience of farm family livelihoods to unanticipated shocks, e.g., weather and price variability – while simultaneously sustaining or increasing the volume of clean water available for downstream use

Theme 2: Water and people in catchments

Theme 2 is concerned with water, poverty and risk in upper catchments. This “catchment” focus is intermediate between plot and whole-basin scales. Within catchments, 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. However, institutions may not be in place to “internalize” important “externalities”, as when upstream land and water management practices affect downstream communities. Theme 2 seeks to identify institutional and technological innovations that improve people’s capacity to manage water collectively, with special attention paid to the needs of women and the poor.

Theme 3: Aquatic ecosystems and fisheries

Theme 3 focuses on fisheries and aquatic ecosystems, their contribution to poor peoples’ livelihoods, the value of the ecological services that they provide, and the ways in which estimates of these values are (or are not) taken into account when decisions are made regarding water use. Aquatic environments are a key source of nutrition for many of the world’s poor. Research under this theme examines environmental water requirements and seeks innovative ways in which to improve the productivity of aquatic ecosystems through policies, institutions, and governance.

Theme 4: Integrated basin water management systems

Theme 4 conducts research on technologies, management strategies, institutional arrangements and decision-support tools compatible with the principles of Integrated Water Resource Management (IWRM). Management strategies are based on the fact that, within a river basin, water resources become available and are used for a succession of purposes, e.g., 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 may 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, where possible, of medium- to long-term processes of change, e.g., population growth, migration, urbanization, economic growth, and opportunities for water development.

Theme 5: Global and national food and water systems

CPWF Theme 5 is concerned with international, national and regional policies and institutions that directly or indirectly influence water and food – and how these policies and institutions can be shaped so that the powerful and ubiquitous processes of global change benefit the poor rather than harming them.

Research within Theme 5 covers two kinds of policies and the links between them: policies specific to the water sector, such as water institutions, economic incentives, and investment strategies; and policies that lie outside the water sector, but indirectly affect water availability and quality, such as those on trade, climate, and macroeconomic issues. This theme also concerns itself with investments and financing for agricultural water development and water supply; transboundary issues, whether defined in terms of national boundaries or boundaries between sectors; and changes in the global water cycle, including opportunities to adapt to these changes.

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 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. Activities and accomplishments related to capacity-building are summarized in a separate section of this report.

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 to invest in further on-farm income raising activities, and 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 . . .
>
> *CPWF synthesis report 2005*

Goal and objectives

CPWF Theme 1 seeks to directly improve crop water productivity by addressing problems of abiotic stress, among them drought, salinity, and nutrient deficiencies. Means for achieving this include crop genetic improvement for stress tolerance; crop, resource and landscape management; and innovative institutions and supporting policies.

In reality, of course, the challenge confronting Theme 1 is much broader. It is not merely to develop technologies that improve crop water productivity – but rather, to do so in ways that increase food security, reduce poverty, and improve the resilience of farm family livelihoods to unanticipated shocks, e.g., weather and price variability – while simultaneously sustaining or increasing the volume of clean water available for downstream use. While increased crop water productivity is important, improved land and labor productivity may be equally important. Ultimately, Theme 1 research aims to enable poor people to benefit from higher levels of production, increased opportunities for employment, and lower food prices.

Theme 1 projects and activities share the common goal of "[helping reduce poverty] through . . . adoptable technology and useable information to help resource-poor farmers to overcome the effects of drought, water-logging and salinity." (CPWF MTP 2006-08)

Participants and partners in Theme 1 aim to reach this goal by realizing four objectives (taken from the CPWF MTP 2006-08):

Plant breeding and evaluation for water-efficient and stress-tolerant crops: "Introducing drought-tolerant varieties will help save water under irrigated conditions and [will greatly increase land and water productivity in rainfed areas] . . . varieties that tolerate water-logging and flooding will reduce the impact of poor drainage on yields. The development of salt-tolerant varieties will enable farmers to make better use of saline land and water."

Water-saving farm practices: "In areas where uneven rainfall results in floods or droughts, improved and well-managed irrigation systems can provide superior water storage and delivery under both irrigated and rainfed conditions. When using irrigation, farmers will be encouraged to reduce water withdrawals by relying as much as possible on rainwater, and in rainfed systems, to introduce supplemental irrigation as dictated by the needs of the crop and the pattern of rainfall."

Need-based water supply: “Some stages of plant growth and development, especially flowering, are extremely sensitive to stress. It is important that supplemental irrigation be available at the right time to achieve high productivity with current varieties, or that new varieties tolerant are produced that tolerate drought or salinity during sensitive stages.”

Policies and institutions: “There is an urgent need for policies and institutions that will give farmers and communities access to the financing needed to achieve the expected gains in production and water savings.”
There is considerable overlap across these objectives. Increased crop water productivity is more likely to be achieved when all four objectives are pursued simultaneously. In drought-prone rainfed environments, for example, the best way to increase crop water productivity may be through a combination of drought-tolerant varieties and water harvesting practices, with suitable support from policies and institutions. Similarly, in salt-affected irrigated environments, success may emerge from a combination of salt-tolerant varieties, changes in crop selection or cropping patterns, land reclamation, improved land and water management practices, and institutional innovations.

Theme 1 activities and outputs are discussed separately for four different production environments: dry rainfed, wet rainfed, salt-affected, and irrigated. Problems, technologies, and research activities vary across these environments.

Improving crop water productivity in relatively dry rainfed environments

There is considerable potential to increase rainwater productivity as well as land productivity in relatively dry rainfed environments. Means to this end include improved varieties, innovative crop and resource management practices, and increased in-field capture of rainfall. Average total annual rainfall in these environments is often enough to produce high yields, but is unpredictable and poorly distributed in relation to crop needs. The beginning of the rainy season may be erratic, there may be extended dry spells, or the rains may finish early, resulting in terminal drought stress.

Several Theme 1 projects focus on rainfed agroecosystems in dry environments. Four projects are located in the Limpopo, Nile and Volta basins of sub-Saharan Africa. The other two are located in areas in the Karkheh and Yellow river basins, in Asia. Most of these projects use an integrated approach that combines new germplasm with crop, soil, water and nutrient management practices; increased use of in-field rainfall; and supporting institutions and policies. The project in the Karkeh also explores potential gains from supplementary irrigation.

CROP IMPROVEMENT

Plant breeding for drought-tolerance and other desirable traits is being conducted in several projects. Breeding is most heavily emphasized in Project PN2 (“*Improving Water Productivity of Cereals and Food Legumes in the Atbara [Nile] River Basin of Eritrea*”), which focuses on the development and selection of improved varieties of barley, wheat, legumes and other crops; soil and agronomic management practices; and the establishment of seed production systems.

Project research has found that, for important cereal and grain legume species in the Eritrean highlands, there is a large interaction between genotype and environment. Production environments (rainfall, temperature, soils, humidity, and disease pressure) vary greatly over short distances. On their own, researchers can identify the best adapted varieties for only a few locations. Moreover, the production of quality seed for the many varieties involved would be beyond the scope of national seed production systems. Participatory methods were identified as essential for local evaluation and selection of germplasm, and for seed increase.

PN2 emphasizes the use of participatory approaches in all aspects of the project: participatory varietal selection (PVS), participatory plant breeding (PPB), farmer experimentation in research on agronomic and water management technologies, and stakeholder participation in project planning, implementation, and evaluation. Because end-user and stakeholder participation is featured so heavily, PN2 participants feel justified in claiming that, “Eritrea [including PN2] is leading the way in participatory research”, and that “farmers are now empowered to make demands on research”. PVS has led to the identification of local landraces capable of greatly increasing yields of barley and Hanfetse (mixed barley/wheat). Germplasm has been identified with the potential to greatly increase wheat, lentil and faba bean, chickpea yields. Backcrossing of desirable traits into locally adapted landraces is underway.

The project has helped develop a mechanism for seed multiplication of superior lines that involves both NARES and participating farmers. Government support has been secured for community seed production of locally selected germplasm. The project is currently working with farmers and extension workers in seven Sub-Zobas (local administrative unit), and has received invitations for collaboration from other Sub-Zobas as well. The first Village Based Seed Enterprise (VBSE) is now operational.

Crop improvement is also an important activity in Project PN6 ("*Empowering Farming Communities in Northern Ghana with Strategic Innovations and Productive Resources in Dryland Farming*") working in the Volta basin. The project has made significant progress in improving the commercial sorghum variety "Kapaala" for yield under terminal drought, and in developing early-maturing cowpea and cassava varieties that can escape terminal drought stress and that have desirable consumer traits. In 2007, PVS for main season cowpea was conducted with over 100 farmers. Six varieties of early-maturing, higher-yielding cowpea adapted to the semi-arid conditions of northern Ghana are being prepared for release in 2008, subject to approval by the National Varietal Release Committee. Four new cowpea cultivars suitable for pre-rainy season cultivation have also been identified.

One practice being assessed by this project is rather curious: the transplanting of sorghum and millet. Participatory trials carried out by 70 farmers in seven communities, using their own sorghum varieties, indicate that transplanting results in earlier harvesting, higher yields (about 50%), and reduced infestation of *Striga* (a parasitic weed that affects sorghum and maize). Understandably, late-maturing lines performed better than early-maturing lines under transplanting. Partial budget analysis, based on farmer trials, showed a 38% increase in returns to transplanted sorghum compared with direct seeding.

Project PN5 ("*Enhancing Rainwater and Nutrient Use Efficiency for Improved Crop Productivity, Farm Income and Rural Livelihoods*") also works in the Volta basin. This project does not engage in crop improvement as such, but rather conducts farmer testing of available new varieties, in combination with alternative soil and nutrient management technologies. It has identified materials that merit further evaluation and dissemination in higher rainfall (maize) and lower rainfall (sorghum, cowpea) areas in Burkina Faso.

Project PN1 ("*Increased Food Security and Income in the Limpopo Basin through Integrated Crop, Water and Soil Fertility Options and Public-Private Partnerships*") is assessing the performance of drought-tolerant, early-maturing varieties of sorghum, maize, groundnut, cowpea and pigeon pea. The project does not engage in plant breeding as such, but rather uses available varieties identified as promising by past research.

PN1 has engaged in on-farm evaluation of varieties and their management in several districts in Zimbabwe, South Africa and Mozambique. Trials were designed and conducted together with local farmers and extension workers, and were tailored to the needs of each location. The trial methodology (1-2 replicates per farmer, many farmer replicates) enabled rigorous scientific comparison of varieties and management factors while simultaneously allowing on-farm evaluation and selection by farmers. A few fully replicated trials to study biophysical processes were also conducted on-station. Through NARES partners, the project has helped increase seed production for new varieties of sorghum, maize, groundnut and pearl millet.

Project PN8, ("*Improving On-farm Agricultural Water Productivity in the Karkheh River Basin*") has identified new genotypes of wheat, barley and lentil that give substantial yield and rainwater productivity increases in comparison with local varieties. This project has also shown that there is substantial variation in the performance of chickpea cultivars for spring and autumn plantings in rainfed conditions and has identified the most desirable cultivars based on yield, seed size and plant height. How well researcher selection of cultivars matches farmer preferences remains unclear.

In summary, several Theme 1 projects have been successful in developing or identifying improved varieties that perform well in relatively dry rainfed environments. Varieties were often identified through some form of PVS. Seed production is either being planned or is already in process. As a rule, however, projects have not as yet provided evidence of widespread farmer adoption

WATER-SAVING FARM PRACTICES AND NEED-BASED WATER SUPPLY

On-farm water management is at the very heart of Theme 1 research in dry rainfed environments. Several projects in Africa and Asia are taking a close look at such practices as water harvesting, soil fertility management, supplementary irrigation, and conservation agriculture.

Five projects in dry rainfed environments in sub-Saharan Africa (PN1, 2, 5, 6, and 17) are assessing the effects on land and water productivity of a range of soil and agronomic management practices. Some of these practices (tied ridges, Zaï pits, half moons, stone rows, and trenches) seek to increase rainfall infiltration by reducing run-off. Other practices (mulching, intercropping) are intended to reduce unproductive soil evaporation. Still other practices, such as fertilizer micro-dosing (very precise applications of small amounts of fertilizer) aim to increase the amount of output per unit of rainfall received.

PN1 is conducting field research in the Limpopo basin on intercropping, mulching, fertilizer micro-dosing, tied ridges and pot holing. Initial results generally show benefits from mulch for growth and yield of maize and groundnut, and considerable response of both maize and groundnuts to application of N fertilizer. A mulch x variety interaction has been observed for groundnut in some environments. One explanation is that, for some varieties, the presence of mulch exacerbates disease.

Little response was seen in PN1 research on pot holing and other methods for increasing infiltration – perhaps due to the sandy (permeable) soils and/or above-average rainfall in the season during which trials were conducted (such practices are most beneficial in relatively dry years). Such findings reinforce the need to evaluate technologies in the agroecological environments for which they are intended, and to define the circumstances within which a technology is expected to perform well. This facilitates scaling out, and reinforces the "international public goods" (IPG) nature of research.

Another project in the Limpopo basin, Project 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*") is assessing comparable practices. Their approach, however, has been to utilize the copious amounts of information that have accumulated over past years (and decades). They report that:

"*Examination of over 10 years of agro-hydrological and agro-economic studies from southern Africa shows that an integrated approach is required . . . recent studies in Zimbabwe and Mozambique show that significant increases in yield can only be obtained when soil fertility management is combined with good crop husbandry, e.g. timely planting and weeding . . . Soil-water conservation approaches, e.g. winter weeding and conservation tillage, can reduce risk and increase yield, as can the application of supplementary irrigation . . . Various soil-water conservation approaches have been developed and promoted for the semi arid areas of Zimbabwe .*

Tillage methods evaluated in this study include deep winter plowing, no-till tied-ridges, modified tied-ridges, clean and mulch ripping, and planting basins [pot holes]. Data collected from the various trials since the 1990s show that mulch ripping and other minimum tillage practices consistently increased soil water content and crop yields compared to traditional spring plowing. Trial results also showed higher soil loss from conventionally plowed plots compared to . . . minimum tillage practices."
(PN17 Annual Report No. 2, September 2005 – August 2006. Page 8)

Project PN5 is studying similar technologies in the Volta basin. Cooperating farmers have been encouraged to select and test new land and water management practices. Farmers chose to test soil fertility management practices (cereal-legume crop rotations, fertilizer micro-dosing); soil and water conservation practices (tied ridges, Zaï pits); and drought-tolerant varieties. Early results show good responses to fertilizer micro-dosing and the replacement of sorghum monoculture with a sorghum–cowpea rotation. PN5 recommends the use of Zaï pits in all areas of Burkina Faso, promotes the use of indigenous rock phosphate fertilizer, and has identified fertilizer options suitable for various levels of financial outlay and resource endowments. The project is active in organizing farmer training in the use of these technologies.

Curiously, most of these practices are already well known in target countries and some were being used by farmers well before the project commenced. What PN5 claims to have done differently has been to study the performance of soil management practices, especially tied ridges, in the context a Payment for Environmental Services program, and to integrate crop, soil and water management improvements with system intensification.

An example of work by PN5 on system intensification focuses on the Sahelian/Sudanian Eco Farm (SEF), developed at the ICRISAT Sahelian Center (ISC) in Niger in collaboration with NARES partners. The SEF is a one hectare field with the following:

- Live hedges of *Acacia* trees planted at 2 meter intervals around the field perimeter
- Rows of trees 10 m apart across the slope of the field, featuring repeating patterns of *Ziziphus Mauritania* (Pomme de Sahel) *Acacia colei* or *Acacia Tumida*
- Semi-circular bunds ("half-moons") placed on contour banks across the field, to collect water, with *Andropogon gayanus* planted to stabilize the bunds
- Cereals grown in rotation with legumes
- Annual crops planted between the rows of trees, on ridges down the slope (with runoff impeded by contour banks)
- Full residue retention
- Crops mulched with *Acacia* prunings after sowing to reduce evaporation

A full SEF field was established at two locations each in Burkina Faso and Ghana. "Mini-SEFs" with selected components are also being tested by 20 farmers. In these tests, sorghum was seen to yield better in rotation with cowpea, *Acacia* provided firewood from annual prunings, and both firewood and Ziziphus fruit were commercially marketed. The full SEFs in Burkina Faso and Ghana are being used as a public awareness mechanism and are visited by farmers and other stakeholders during open days and exchange visits. Adoption by farmers who have visited the full scale plots is to be monitored in the future. To date, evidence of farmer adoption has not been made available.

PN6 also works in the Volta and in close collaboration with PN5. It has conducted farmer-managed adaptive trials in four villages on ridging and soil fertility management practices, and their effect on sorghum yields and soil and water conservation. Little information is available, however, on farmer feedback or adoption of these practices.

In Eritrea, PN2 conducted on-farm evaluation of nitrogen fertilizer use and measures for increasing rainfall infiltration and conserving soil moisture conservation (tied ridges, weeding). This was done on three very different soil types. Over two seasons, there were consistently large responses to fertilizer and smaller responses to tied ridges and weeding. Surprisingly, however, no interactions were observed. This suggests either that water availability is not limiting or, more likely, that there are other constraints to crop water use that need further investigation.

The projects described above all focus on sub-Saharan Africa. There are two other projects, located in Asia, which also study land and water management for crop production in dryland environments. One is located in Iran and the other in China.

The first of these is Project PN8, ("*Improving On-farm Agricultural Water Productivity in the Karkheh River Basin*"), in Iran. The focus of PN8 is not on water harvesting but rather on supplementary irrigation. Working in the upper Karkheh basin, the Project has assessed, for improved varieties of wheat and barley, the effects on land and water productivity of a single supplementary irrigation at a single key plant growth stage: either sowing, flowering, or grain-filling. Results show a dramatic impact of a single irrigation on both yield and water productivity: a single irrigation was found to increase barley yield by 35-46% and total water productivity (irrigation plus rainfall) by 22-31%. However, the optimum timing for the single irrigation varies with location. It is unclear to what extent spatial patterns of water availability for supplementary irrigation will affect the feasibility of this technology in different parts of the upper basin.

The second project is 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*"), in China. This Project adapts and tests conservation agriculture (CA), a combination of zero or reduced tillage, residue retention and crop rotation. The inspiration for this project comes from the success of CA and related technologies in South America and South Asia, and builds on earlier work by Chinese institutions and ACIAR within China.

The Yellow River basin extends over several Provinces of China and is characterized by extensive soil degradation and compromised hydrologic cycles – at one stage during the previous decade, the river practically ceased flowing. PN12 conducts research on dryland systems in five basin Provinces: Shandong, Henan, Shanxi, Ningxia and Inner Mongolia. Over the past three years, PN12 has carried out participatory trials, demonstrations and replicated experiments on CA in all five Provinces. These have explored various combinations of residue retention, reduced or zero tillage, and improved crop rotations.

It was found that the design of CA must take account of moisture, temperature, and the presence of livestock. CA is more difficult to implement in the relatively cold, dry Provinces of Inner Mongolia, Ningxia and Shanxi. Here, residue retention and mulching lower soil temperatures, impede crop germination and reduce yields. Moreover, residues are scarce in these Provinces: little residue is produced and this is used for livestock feed. Farmers have learned to use a plastic film for "mulch"; this fosters soil warming and moisture retention. PN12 has developed a modified system which combines CA with the use of plastic film: straw mulch is used *between* crop rows and plastic film *in* the rows. No-till direct sowing is done into the plastic film. Early results show that soil water content and yields are comparable or higher in the modified CA system compared to conventional practices using full tillage and plastic film.

Faster progress with CA is being made in the relatively wet, warm southern Provinces of Shandong and Henan. Here, the Project is developing double cropped CA systems for rainfed areas (wheat-maize in Shandong and wheat-soybean in Henan). Detailed monitoring is being conducted at several sites for a wide range of parameters including soil water, soil temperature, and other soil biological, chemical and physical properties; crop growth and yield. Results consistently show that mulching increases soil water.

CA adoption has been concentrated in Shandong. The area covered by CA in rainfed wheat-maize systems in Shandong has grown from about 4,000 ha in 2006 to about 13,000 ha in 2007 (about 1% of rainfed harvested area). In the other provinces, CA is being demonstrated or adopted on relatively small areas.

A comprehensive survey conducted by the PN12 team raises a concern. Individual CA components have been adopted here and there in rainfed areas, but the simultaneous adoption of all three (zero tillage, residue retention, new rotations) is uncommon. Findings from maize-wheat systems in Mexico, however, suggest that adoption of *all* components is essential: in fact, the adoption of individual components can in some instances be detrimental. In one example, zero tillage without residue retention led to substantial yield declines in maize-wheat systems.

Surveys have identified three factors that favor farmer adoption of CA: enforcement of government restrictions on residue crop burning, scarcity of family labor, and the presence of subsidies for equipment purchase. General adoption of CA is constrained, however, by a lack of suitable implements. The project has made progress on machinery development and promotion through collaboration with two machinery companies, whereby 35 no-till seeders have been manufactured. These have multi-crop capability: they can sow a range of seeds from maize to wheat. The project has also developed a permanent-raised-bed zero-till planter and bed former, which has yet to be introduced commercially. The project team has also provided training to around 2000 farmers and has distributed information handbooks to many thousands more.

In summary, there is considerable commonality across projects and basins in exploring water-saving practices. Pot holing, tied ridging and other on-farm water capture practices are topics for research by several projects in different parts of sub-Saharan Africa. Mulching is a priority topic in both Africa and Asia. A more systematic comparison of results across projects might be in order.

POLICIES AND INSTITUTIONS

One Theme 1 objective featured in the 2006-08 MTP was the development of “policies and institutions that will give farmers . . . access to the financing needed to achieve the expected gains in production and water savings.”

In dryland environments, CPWF projects have emphasized policies and institutions related to input and product markets, seed supply systems, fertilizer packaging and availability, and access to microcredit. PN1 and PN5 have conducted surveys to identify potential opportunities for improving farmer-market linkages in project areas in Zimbabwe, South Africa, Ghana and Burkina Faso. They have also undertaken reviews of approaches to improving farmer access to micro-credit and input markets.

PN1 evaluated a range of models for seed production and input supply. It concluded that there is considerable potential for expanding micro-credit facilities and improving input supply (availability, quality, range of package sizes) in South Africa. Research by an allied project showed that smallholder farmers in that country are more likely to try fertilizer when supplied in small (more affordable) packages. Moreover, once farmers start using small amounts of fertilizer, they gradually begin to increase the amount applied. To date, two companies have agreed to make fertilizer available in packs of 5, 10 and 20 kg.

PN1 and PN5 also explored the use of micro-credit based on “warrantage systems”. A warrantage system enables farmers or producer organizations to “mortgage” their production of cereal grains at harvest time and secure a loan to carry out income-generating activities during the off-season. In this way farmers are not compelled to sell what they produce at the relatively low post-harvest grain price. “Mortgaged” grain is stored in a clean, secure place. Farmers may sell some of their grain when prices rise, or (after re-paying their loan) retrieve it for home consumption.

In the Limpopo basin, one private company, Progress Mills, already has many depots that provide farm services through a warrantage system. In the Volta basin, farmers in two communities in Burkina Faso are responding positively to trials of the warrantage system. They see particular value in avoiding food shortage during the pre-harvest “hungry period” when prices are high. Agreements have been signed between the project, farmers, and the Caisse Populaire (a credit institution) regarding credit access. Training has been conducted for warrantage committee members. Guided by the findings of the PN5 team, and with support from a new donor (PDRD – Program for Sustainable Rural Development), plans have been developed to set up warrantage systems in five new communities in Burkina Faso.

In the Nile basin, Project PN2 is engaged in encouraging the development of Village Based Seed Enterprises (VBSE), an institutional innovation designed to serve as a mechanism for multiplication and distribution of seed of locally selected, superior germplasm. The project has achieved community and Ministry support.

Finally, in the Yellow river basin, Project PN12 is exploring the effect of subsidies on farmer adoption of conservation agriculture implements – and some of the unanticipated effects of subsidy policies: “. . . current Chinese mechanization policy focuses attention on equipment for medium-large tractors, e.g., 50+ hp, whilst small farmers require adapted direct planting equipment for small tractors, e.g., 25 hp . . .”. PN12 seeks to influence policy to promote conservation agriculture through a range of mechanisms, including inviting officials of the Ministry of Agriculture and Provincial and Local Governments to visit field demonstration sites, participation in provincial meetings on machinery subsidies, participation in the development of the conservation agriculture blueprint for the 11th Five Year Plan, and discussions with the Minister of Agriculture.

COMPLEMENTARY ACTIVITIES: BASELINE SURVEYS

Most Theme 1 projects have carried out activities that complement those described above. These activities are for the most part related to information management, scaling out and risk assessment. They include baseline surveys, the delineation of agroecological zones, and the calibration and use of simulation models.

A good example is Project PN1. This project has made a major investment in a comprehensive baseline survey, whose objective is to “ . . . set priorities for points of intervention . . . ; establish baseline levels of farmers’ knowledge, levels of adoption and constraints to uptake of improved crop, water and soil fertility technologies; establish baseline levels of farmers participation in input and output markets, access to credit, extension market information and social networks; [and] establish baseline on effects of HIV/AIDS on smallholder livelihoods including crop management practices . . .” Formal surveys were completed for about 1000 households distributed across 48 villages, in each of two countries, Zimbabwe and South Africa. Data was collected during 2004-2005, with results becoming available during 2007. Some results are summarized below:

Demography: Households in South Africa and Zimbabwe both had a mean size of six members. Female headed households were smaller than male headed households. Unlike Zimbabwe, few household members in South Africa worked fulltime in agriculture.

Literacy: Literacy levels of household heads were higher in Zimbabwe than in South Africa. Male heads of households had higher literacy levels than female heads.

Disease: At least 20% of households in sampled districts in both South Africa and Zimbabwe had at least one household member who was chronically ill. A significant proportion of household heads were chronically ill in all sampled districts.

Food security: In both South Africa and Zimbabwe, about 95% of sampled households were not able to produce enough grain to last till the next harvest.

Implements: In South Africa, most sampled households owned a hoe, but fewer than 10% owned a plow and less than 5% owned draft animals. In Zimbabwe, 65% of households owned a plow, and 30% owned draft animals. In both countries, implement ownership was more common in male-headed households.

Cattle: A larger proportion of households in Zimbabwe owned cattle than in South Africa. More than 70% of households in Zimbabwe owned goats. Female-headed households were less likely to own cattle, or owned smaller herds.

Cropped area: In both countries, maize was the most common crop. Legumes were not widely grown. In South Africa, harvested area for all crops was around 0.5 ha per household and in Zimbabwe about 1.6 ha. Households with draft animals planted a larger area. Households with chronically ill members planted smaller areas.

Manure and fertilizer: More than 70% of households were acquainted with manure as a means of managing soil fertility, but only 20% actually applied manure in their fields. Fewer than 20% of households used fertilizer. Fertilizer users applied very small amounts, less than 10 kilograms per household. Male headed households applied more than female headed households.

Yields: Maize yields averaged less than 100 kilograms per hectare in Zimbabwe. Sekhukhune district in South Africa recorded the highest yield of 540 kg/ha followed by Mopani with 459 kg/ha. Mean cereal yields were higher with fertilizer.

Sources of income: Social welfare support from government and pensions were the major sources of income for South African households. Remittances and off-farm employment were the main sources of income for the households interviewed in Zimbabwe. With few exceptions, male headed households had higher income levels than female headed households.
Baseline survey results provide a descriptive standard

against which project progress can be measured. It is not clear, however, to what extent results have been used in examining constraints to technology adoption, or in setting research priorities.

Surveys of on-farm conditions in the Limpopo have also been conducted by PN17. Survey results reveal that farm family livelihoods and well-being are influenced by climate variability, geographical location, economic shocks, employment opportunities, impact of HIV/AIDS, market access, and government policies governing water management. In areas within Zimbabwe, “A significant population still relies on farming as a livelihood source but most income is realized from goat sales, not cropping. Despite this scenario, interventions are still heavily directed [towards] short-term relief rather than long-term development initiatives that can alleviate poverty and provide livelihood security.”

Some PN17 survey findings confirm those from the PN1 survey. Other findings shed light on issues not explored by PN1. Taken together, the two surveys are complementary and when combined with BFP findings could provide the foundation of a basin-specific research synthesis.

Few other Theme 1 projects working in dryland environments have dedicated this level of effort to baseline surveys. PN6 (Volta) did release a report on farm conditions in the project area regarding household assets, income, expenditure, health, education, and access to and use of water. Project PN5 (Volta) undertook participatory rural appraisals in four villages in Ghana and two in Burkina Faso. These touched on soil fertility (poor), water supply (inadequate), organic fertilizer use (restricted to plots near the household), mineral fertilizer use (perceived as too expensive), and access to markets (poor).

COMPLEMENTARY ACTIVITIES: SPATIAL ANALYSIS AND SIMULATION MODELS

Projects PN1 and PN8 both used GIS to develop agro-ecological zoning for site similarity analysis. In the case of PN1, the intention was to have an objective basis for selecting representative benchmark sites for research in the Limpopo basin. In the case of PN8, the intention was to conduct a retrospective assessment of the similarity of pre-selected benchmark sites in the Karkheh basin with the broader outside world. This was done at three scales: Karkeh basin, Iran, and Central and West Asia and North Africa (CWANA).

PN1 claims to have used spatial information to target public and private sector investment in smallholder development. Support for smallholders in the production and marketing of high-value, perishable commodities, for example, can be targeted to areas with favorable climate and soils, low marketing margins and good market access.

PN5 used remote sensing to generate land use maps of study areas in the Volta basin, while PN6 completed a “drought probability map” for northern Ghana, using data from geo-referenced weather stations. For 22 locations, monthly drought probabilities for June – September were calculated, then the spatial distribution of drought prob-

ability, timing of the onset of rains and length of growing season, were estimated.

PN5 helped build the capacity of African scientists to use crop simulation models. The project collected data for model calibration, compiled weather data sets and calibrated and adapted the DSSAT-Century and APSIM models for sorghum. These models were used to assess the climate-related risk of different land and water management strategies (N application, crop residue management) in terms of land and water. A book is being prepared containing DSSAT simulations of various crop-water-soil and nutrient management scenarios.

PN12 (Yellow River) has calibrated the DSSAT model for a maize-fallow-maize rotation with CA treatments ranging from complete residue removal with conventional tillage to mulching with zero tillage. Over a period of 10 years, the model predicted that CA treatments result in higher yields (by up to 36%), decreased runoff (by up to 98%), and increased crop water productivity (by 5 to 28%) in comparison with residue removal followed by conventional tillage.

Finally, PN8 used a GIS-based surface water balance method to map runoff and to identify potential priority areas for supplemental irrigation in the upper Karkeh River Basin. The impacts of adoption of supplemental irrigation on downstream water flows were determined for a single autumn (sowing) or spring (flowering-heading) irrigation. Spring irrigation had less effect on downstream flows than autumn irrigations. They also evaluated the potential irrigable area for a range of environmental flow rules including: no rule, 15% reduction in mean annual runoff, and reduction of one standard deviation.

IN SUMMARY

In summary, several projects used baseline surveys to characterize study areas, spatial analysis to assist in technology targeting, or simulation models to explore the performance of different technologies under future conditions. However, there appears to be only one example of a project looking at the downstream consequences of the adoption of new technologies.

Improving crop water productivity in relatively wet rainfed environments

Only two Theme 1 projects conduct research on water productivity in relatively wet rainfed environments. These are Project PN11 ("*Rice Landscape Management for Raising Water Productivity, Conserving Resources and Improving Livelihoods in Upper Catchments of the Mekong and Red River Basins*") and Project PN15 ("*Quesungual Slash-and-Mulch Agroforestry System (QSMAS): Improving Crop Water Productivity, Food Security and Resource Quality in the Sub-humid Tropics*"). The former project works in the Mekong basin. The latter project works in the Lempa River upper watershed, Honduras; the La Danta watershed, Nicaragua; and the upper watershed of Cauca River in Colombia, in the Andes.

Rainfall in these regions is often of high intensity, particularly at the start of the rainy season. Hillside slash and burn systems used by farmers are susceptible to soil erosion, resulting in lower soil fertility, reduced food production, and pollution of downstream water supplies. As populations expand, fallow periods (re-establishment of secondary growth forest) are further shortened, slash and burn systems are pushed further up the slopes, and negative impacts are felt across the landscape. Farmers are caught in a downward spiral of land degradation, poverty and reduced production.

Although PN11 and PN15 are located on opposite sides of the globe, they share common concerns: how to reduce poverty, improve farm family livelihoods, reduce soil erosion and land degradation, and enhance the productivity of land and water in sloping upland areas that receive relatively high levels of rainfall (often in the 1000 – 1800 mm per year range). Despite sharing common concerns, the two projects employ rather different means of dealing with them.

CROP IMPROVEMENT

Project PN11 targets the rainfed uplands of Laos, northern Thailand, and northern Vietnam, where agroecosystems are rice-based and rice is the principal food staple. In these regions, transplanted, puddled rice is grown in river valleys (sometimes but not always with irrigation) while upland rice is grown on lower slopes where soils are relatively poor and fragile, and water is limiting.

PN11 seeks to use improved varieties as a key entry point for improving crop yields and water productivity. The project does not engage in plant breeding as such; rather it takes existing materials and makes them available for farmer testing and selection. The project is testing a number of new rice cultivars and management practices, each matched to particular growing environments, cropping patterns, local preferences or market conditions. Cultivars and management practices may be targeted at uplands or lowlands, wet or dry season sowing, or systems with single or multiple-cropping. Varieties may be of early or late maturity, or have glutinous or non-glutinous grain quality. They may be hybrids or normal materials and, if the latter, they may be more suitable either for lowland anaerobic conditions or for aerobic conditions.

In this context multiple factors must be taken into account when evaluating new varieties. In the areas being studied by PN11, these include moisture stress tolerance, cold tolerance, ability to fit into the cropping pattern, and other traits that farmers find desirable. Clear opportunities to improve rice yields through varietal change – without increasing water use – have already been identified. In Vietnam, good progress has been made in identifying upland and lowland rice varieties that perform well with little to moderate fertilizer inputs.

In 2007, the project commenced upland and lowland "community rice seed production" programs to enhance the availability and dissemination of quality seed. PN11 will train some extension agents and farmers in scientific seed production principles and practices. Besides laying foundations for community-level seed production and enhancing seed availability, the seed production program is envisaged to enhance farm household income, and improve capacity of extension agents and farmers for continuity of community-level seed production into the future after the termination of the project.

In Project PN15, crop improvement for food staples (maize and beans) is not a major activity. Rather, the emphasis is on a version of conservation agriculture based on slash and mulch practices, direct seeding, and efficient use of fertilizer.

WATER-SAVING FARM PRACTICES AND NEED-BASED WATER SUPPLY

Even in relatively wet rainfed environments, water can be scarce at some times for some users. In the regions targeted by PN11 and PN15, the rainy season lasts for about six months, but there may be prolonged dry periods after the first rains, and erratic, low-intensity rainfall toward the end of the rainy season during critical stages of grain filling. PN11 has found that water may be abundant in one part of a catchment, and scarce in another. In the Thailand site, for example, "Water availability for crops i s more of a problem for lowland households than for upland households . . . Water use conflict is almost absent in the uplands." (PN11 Annual Report, January-December 2006.)

Be that as it may, "water scarcity" is relative. Farm families in the Limpopo or Volta may consider that water is abundant if their crops are not affected by drought. In contrast, farmers in the Mekong uplands may feel that water is scarce if there is not enough to cultivate puddled rice. Certainly, one constraint to expanded terracing for paddy rice is lack of water (others are construction expense and the limited area suitable for terracing).

Where water is scarce, water productivity remains important. One promising way to improve water productivity in PN11 study areas is through system intensification and diversification (more value of output per unit rainfall depleted). The project is exploring options for increasing water productivity through improved varieties, improved management of lowland rice (fertilizer use), and double cropping (through direct seeding of shorter duration varieties). Not all households have access to lowland rice fields, however. Some only have access to sloping land. Research for these households focuses on increasing the productivity of upland rice, and improving soil management.

It might be argued that erosion control is even more important than soil moisture conservation in sloping uplands. In the Vietnam site of PN11, trials are being conducted on the use of mulch from crop residues to improve yields and reduce erosion. However, it is Project PN15 that really emphasizes the use of mulch for erosion control and water conservation purposes.

PN15 is being implemented in Honduras and Nicaragua, with a recent expansion of activities to Colombia. It studies 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 controlled through community-led collective action. This project shares a number of elements – permanent soil cover and direct sowing with zero tillage – with project PN12. In PN15, however, soil cover is based on slashed forest vegetation while in PN12 soil cover comes from crop residues.

It should be noted that the *Quesungual* technology emerged from the multi-year "FAO-Lempira Project" in Honduras and is largely farmer-developed. PN15 research has focused less on technology development *per se* and more on answering questions such as:

- What are the key principles of QSMAS: No burning; permanent soil cover; minimal soil disturbance; efficient use of fertilizer
- What is the extent of adoption? Approximately 7,000 farmers on 6,000 ha, largely in Honduras
- What are some consequences of adoption?

- Reductions in: runoff, erosion, water turbidity, surface evaporation, production costs
- Increases in: earthworm populations, infiltration, soil water storage capacity, soil carbon, water productivity and crop yields
- Improvements in: soil quality, structure, biological activity, organic matter, fertility and fertilizer use efficiency
- What are factors governing adoption? Collective action to prohibit burning practices, incentives to foster integration with markets
- How might these practices be further scaled out? Spatial analysis to identify other areas in the world where this system may be appropriate. (Note that farmer-to-farmer information exchange is already being used to foster adoption in Nicaragua.)

POLICIES AND INSTITUTIONS

The two Theme 1 projects in relatively wet rainfed environments see a role for policies and institutions in accelerating the adoption of improved practices. Project PN11 anticipates that policy interventions as well as technical interventions will be developed to overcome constraints to the productivity of rice-based systems, and that (undefined) institutional innovations for water sharing and water use can help improve poor people's access to water. Policies to improve market access can be powerful ways to help farm families escape from poverty (see next section). For future efforts on the scaling out and scaling up of Quesungual system, project PN15 contemplates fostering a favorable policy environment to promote the introduction of Quesungual systems as an alternative to traditional slash and burn.

Complementary activities: baseline surveys

Just as is the case in dryland environments, Theme 1 projects in wet rainfed environments are conducting complementary activities, among them diagnostic and baseline surveys, spatial analysis and simulation modeling.

A baseline survey was conducted by PN11 that emphasized a comparison between two Laotian villages, each with different resource endowments. Survey results indicate that livelihood strategies are quite different between the two villages. In one village, where most farmers have access to sizeable lowland rice fields and good access to markets, livelihood activities are rapidly becoming more diversified. Upland areas are shifting out of rice and into cash crops, and farmers are generating substantial income from livestock production and non-farm activities. A single crop of lowland rice provides an adequate food supply for the village. Water constraints do not allow double-cropping.

In contrast, in the other village, farmers have fewer and smaller lowland fields and market access is more difficult. Upland rice production remains an important activity, production systems are less diversified, and non-farm income is lower. Lowland fields are smaller but are more intensively utilized (fewer water constraints). Per capita income is about one-third of in the first village. Food security is especially precarious for smaller farmers with no lowland fields. Access to markets and lowland fields appear more important than access to water in explaining the difference between livelihood activities and incomes levels in these two villages.

Survey results suggest that interventions targeted to rice need to be complemented by promotion of income-generating activities through cash cropping, livestock management or off-farm income. Farmers currently investing in such activities are on a pathway out of poverty, as long as they are adequately supported by market development. Marketing systems are very weak in these upland areas, however, and public sector interventions to support market development are of high priority.

Complementary activities: spatial analysis and simulation models

Different Theme 1 projects have different purposes for using spatial analysis or simulation modeling. In dryland areas, models are used to assess the riskiness of different technologies in variable climates. In wetter areas, there is greater emphasis on hydrology, and modeling the downstream consequences of upstream interventions. The most common use of spatial analysis is for technology targeting.

PN15 uses spatial analysis to help identify other areas in Latin America suitable for the introduction of *Quesungual* systems. They suggest caution, however, in designing scaling out activities. Although some general principles of QSMAS are transferable, for example, no-burning and no-till management combined with soil cover, scaling out must often be done in the context of a long-term framework. Changes in social capital take much more time than changes in other kinds of capital.

PN11 has made a substantial investment in information management. Secondary data have been collected for general land use, water resources, rice yields, cropping calendars, demographic structure and poverty status. A

GIS platform has been built for the Houay Hom watershed and spatial data have been gathered on land use, elevation, village locations, roads, streams and rivers, soils, etc. from a range of sources including participatory land use and resource mapping. Hydrological data on stream flow, paddy water depths, soil water and meteorological data have been collected at several locations in the catchment, for use with the MIKE SHE simulation model to assess the downstream and cross-scale consequences of introducing alternative land and water management scenarios and strategies. The hypothesis is that changing from frequent slash and burn and cultivation of annual crops to perennial vegetation will increase water availability or timeliness of supply for rice production in terraces on the lower slopes.

IN SUMMARY

In summary CPWF projects in wet rainfed environments report considerable progress in varietal selection, development of seed systems, scaling out of direct sowing and mulching, and poverty reduction through policy for improved market access for smallholders. In future synthesis documents, more information may be available on how this unfolded: which varieties were selected by farmers, how much seed was produced and distributed through the new seed systems, how sustainable the new systems proved to be, what was the magnitude of new adoption of direct sowing and mulching, and which market policies favored which (and how many) farmers – and what was the role of the project in fostering policy change.

Improving crop water productivity in salt-affected environments

Salinity is an important issue for Theme 1, especially in rainfed lowland rice-based systems in the eastern Ganges, in irrigated environments affected by secondary salinization in the Indus and Karkheh basins, and in coastal areas of the Ganges, Mekong and Nile basins. Approximately 21m ha of agricultural land in Asia are salt-affected, including 9m ha of saline/sodic soils. Salt-affected lands may be inland, with severely affected and partially reclaimed saline/sodic soils, or in coastal areas. They are typically left barren, or planted during the wet season with local rice varieties with high salt tolerance but low yield potential. Salinity stress is exacerbated by drought regardless of whether it occurs at crop establishment or during the growing season. Salinity problems undermine food security and livelihoods for an enormous number of poor people.

CROP IMPROVEMENT

Crop improvement for salt-tolerance is being done by two CPWF Theme 1 projects working in four basins. In the salt-affected areas of the lower Karkeh basin, Project PN8 is evaluating wheat, fodder sorghum and barley genotypes for salt tolerance, and is examining irrigation methods and sowing methods for irrigated crops on salt-affected soils. Most work on salt tolerance, however, is being done by Project PN7 ("*Development of Technologies to Harness the Productivity Potential of Salt-Affected Areas of the Indo-Gangetic and . . . Mekong Basins*").

Many crops are sensitive to salt. Rice, for example, is sensitive to salinity at both seedling and reproductive stages. PN7 is making good progress in developing rice and non-rice varieties for salt-affected areas in the Indo-Gangetic and Mekong basins. In these areas, rice is grown during the wet season and is predominantly rainfed. Supplementary irrigation is occasionally used by some farmers with irrigation to "finish" a crop.

Advances in crop improvement for salt-tolerance include: progress in understanding salinity tolerance mechanisms for rice and non-rice crops; the development of rapid methods for screening for salt tolerance; the identification of markers for market-assisted selection (MAS) for the major QTL (Saltol) associated with salt tolerance in rice; and the use of MAS to accelerate efforts to incorporate salt tolerance into locally preferred, adapted, high yielding varieties. Saltol, which can now be introduced into rice varieties within 2-2.5 years, has already been incorporated into one Bangladeshi variety (BRRI dhan28-*Saltol*), and efforts are underway to introduce it into several others.

Rice in salt-affected areas typically also suffers from other abiotic stresses, such as zinc deficiency and iron toxicity. PN7 has undertaken a crossing program to develop lines with zinc use efficiency, and with tolerance to multiple abiotic stresses. Work has recently commenced on the development of lines with tolerance to both salinity and submergence: farmers in coastal salt affected areas often face both problems.

Early maturity is a key trait being incorporated into improved varieties of rice for rainfed, salt-affected areas. Early maturity can reduce the effects of terminal drought when rains cease early, and can actually make the difference between getting some yield and no yield at all. It can help save water by reducing the amount of irrigation needed to finish the rice crop after the rainy season has ended. Shorter duration rice varieties can also facilitate the sowing of crops after rice, using residual moisture. This helps avoids pre-sowing irrigation and allows timely establishment, resulting in higher yields and better crop water productivity of the post-rice crop and the total cropping system.

PN7 is helping to develop and evaluate salt-tolerant crops other than rice. Advances include the development of techniques for screening pigeon pea, groundnut and fodder crops for salt tolerance; the development of salt tolerant varieties of sorghum and pearl millet; and the evaluation of salt-tolerance in barley, triticale, safflower and fodder crops. Screening of groundnut, chickpea and pigeonpea genotypes has identified parents for breeding for salt tolerance. The project has achieved improved understanding of the mechanisms of salt tolerance in these crops which will lead to more efficient identification of and breeding for salt tolerant germplasm.

Varietal requirements for both rice and non-rice crops demonstrate great spatial variation. They are influenced by numerous factors including soils, climate, cropping practices, plant type and grain quality preferences, and other socio-economic features. Localized varietal evaluation and selection by farmers are therefore essential. PN7 has launched a PVS program featuring a range of salt tolerant, high yielding rice and non-rice genotypes. This program is active in several locations in India, Bangladesh and Vietnam. Initial efforts to increase seed of superior genotypes have begun in some project sites. In 11 districts of a coastal salt-affected area of Orissa, India, about 300 farmers have begun growing sunflower, watermelon, chili, okra, and groundnut using seeds provided by PN7. The demand for seed for non-rice crops is increasing rapidly.

WATER-SAVING FARM PRACTICES AND NEED-BASED WATER SUPPLY

Project PN7 is developing crop and resource management strategies and cropping systems that complement salt-tolerant varieties and that increase water productivity for both the rice crop and the total cropping system. Some of these technologies also reduce the water input for rice.

Farmers operating on saline/sodic soils often cannot afford the gypsum treatment typically recommended for soil reclamation. NARES institutions collaborating with PN7 have long been aware of this problem and succeeded in developing, even before project initiation, a range of low-cost reclamation methods. These include the use of green manures, industrial by-products, and low application rates of gypsum (25% of recommended). NARES also developed practices for increasing rice yields in salt-affected soils, involving changes in nutrient, transplanting and rice nursery management. Such practices become more feasible when combined with salt-tolerant varieties because these are more responsive to improved management. PN7 is helping scale out these technologies by integrating them into PVS programs.

PN7 is also evaluating water/irrigation management in salt-affected soils, and has identified water management practices that maintain yields while reducing water input. The project has found that continuous flooding is not necessary to maintain high yields on coastal and inland salt-affected soils. This suggests that there is a large potential to significantly reduce irrigation water use. The project is also exploring the potential benefits of direct seeding of rice. This enables rice to be sown and harvested earlier, and facilitates timely sowing of post-rice crops like wheat. Sowing wheat on time increases yields and reduces irrigation requirements as the wheat matures during cooler weather with lower evaporative demand. Good salt tolerance during the early seedling stage is important for rice direct seeding.

A combination of tolerant varieties and improved management practices can result in higher rice yields and substantially higher water productivity. They can also reduce the likelihood that farmers will abandon salt-affected fields in mid-season. In drier years, farmers sometimes do abandon these fields, even after having applied two or three irrigations, as they cannot afford the cost of continued water pumping. The shorter duration, high yielding genotypes that PN7 is producing will help save water and increase water productivity by raising yields and reducing irrigation requirements.

POLICIES AND INSTITUTIONS

PN7 has established an effective network for exchange of genetic material and knowledge of the performance of this material in salt-affected environments. This includes the establishment of a special International Rice Soil Stress Tolerance Nursery (IRSSTON) for coastal saline and inland and sodic areas, within the Consortium for Unfavorable Rice Environments (CURE). CURE was established in 2002 as a vehicle for linkage between IRRI and NARES in selected countries in Asia for joint research activities in rainfed rice in unfavorable environments.

COMPLEMENTARY ACTIVITIES

Within PN7, benchmark studies have been completed. Reports from India and Bangladesh have been compiled and submitted while similar reports are in progress in Vietnam and Iran. Data collected cover biophysical characteristics of salt affected areas, constraints to rice cultivation, information on farmers' practices, innovations in coping with stresses, constraints to adoption of improved technologies, land holding size, sources of irrigation, prevailing dominant cropping systems and crop varieties and cultivation cost, among others.

The project included identification of gender issues in the initial problem diagnosis. A PRA was used to identify gender disparities in access to education, agricultural information, and the labor contributions of adult males and females in rice production. This information revealed that female members of farming households play important roles in growing rice. Women farmers are involved as farmer cooperators in PVS and scaling up of varieties and crop management technologies for salt-affected areas. Many were involved in the training on improved seed health practices.

Finally, PN7 is collecting information on river and groundwater salinity levels in salt affected coastal areas in Orissa and Bangladesh, with a view to identifying the potential for supplementary irrigation and designing cropping systems (rice-rice, rice-non-rice) to match the available water resource in terms of quantity and salinity.

Improving crop water productivity in irrigated environments

Theme 1 projects in dry rainfed areas are concerned with increasing crop water productivity in the face of drought stress and low soil fertility. These projects are mostly located in sub-Saharan Africa. Theme 1 projects in wet rainfed environments, based in Latin America and Southeast Asia, tend to focus on erosion and resource degradation.

In contrast, Theme 1 projects in irrigated environments are concerned with increasing crop water productivity so as to help improve food security, incomes and livelihoods, while conserving the environment. There are two such projects. The first of these is PN8, working in the Karkheh basin. This project has assessed water productivity for irrigated wheat and maize in the lower Karkeh River Basin, using irrigation water from different sources (well, irrigation network, pumping from river, combination of well and network). Water productivity (irrigation + rainfall) in wheat production ranged from 0.5-1.8 kg/m^3. Mean yield (5.5 t/ha) and water productivity (2.6 kg/m^3) were higher when crops drew on a combination of water sources.

Most work on crop water productivity in irrigated systems, however, was conducted within project PN16, ("*Developing a System of Temperate and Tropical Aerobic Rice (STAR) in Asia*"), working in East, South and Southeast Asia. This project ended during 2007.

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 high rice yields – with only 50-70% of the water typically required for puddled rice systems. 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. Water in irrigated areas becomes scarcer when there is simply less of it (declining groundwater tables, siltation of reservoirs, diversion of water to competing users); its quality has deteriorated (chemical pollution, salinization); or it has become more expensive to use (cost of pumping).

CROP IMPROVEMENT

Within the CPWF, aerobic rice systems have been studied by PN16. Breeding and evaluation of aerobic rice for water-scarce irrigated environments began in the 1980s by China Agricultural University in selected rice-growing regions of the Yellow River Basin. Collaboration with IRRI began in the late 1990s through the Irrigated Rice Research Consortium (IRRC) and the Consortium for Unfavorable Rice Environments (CURE). PN16 built on this work. In partnership with IRRC and CURE, it helped evaluate and select varieties for a range of new target environments including the sub-tropical, irrigated regions of the Ganges River Basin in India, favorable rainfed uplands in Laos and Thailand, and tropical irrigated lowlands in the Philippines. Varietal evaluation included on-station trials, researcher-managed on-farm trials, and PVS in farmers' fields.

Breeding of aerobic rice is most developed in China where varieties have been released for temperate rice growing areas in the Yellow River Basin. Yield potential of 6 t ha^{-1} (HD502, HD297) has been demonstrated in relatively dry soils with soil water tensions up to 100 kPa. In the sub-tropical environment of the western Ganges, aerobic rice varieties with 4.5 t ha^{-1} yield potential have been identified (Pusa Rice Hybrid 10, Proagro6111, Pusa834, Apo (PSBRc9) when grown at soil water tensions up to 30-40 kPa. In the Philippines, varieties with a yield potential of 6 t ha^{-1} (Apo, UPLRi5, Magat) have been identified. However, these varieties have a relatively lower tolerance to dry soil conditions than Chinese varieties: soil water tensions had to be kept below 30-40 kPa to reach these high yields. Under rainfed conditions in Laos and northeast Thailand, breeding lines were identified with yield potentials of 2.0 and 3.5 t ha^{-1}, respectively.

WATER-SAVING FARM PRACTICES AND NEED-BASED WATER SUPPLY

Aerobic rice systems can yield well while using far less irrigation water than lowland rice systems. In rice areas near Beijing, for example, continuously flooded, puddled transplanted rice has a typical irrigation requirement of around 1000 mm. In controlled field experiments in the same areas, aerobic rice yields (variety HD297) have reached 5-5.6 t ha^{-1} with 600-700 mm total irrigation plus rainfall. At 450-550 mm irrigation input, aerobic rice yields declined to 2.5-4.3 t ha^{-1}, finally dropping off to 0.5 t ha^{-1} when the soil was very dry around flowering (soil water tension higher than 100 kPa). The lesson is straightforward: if there is no rain, at least some irrigation is essential at flowering time.

With shallow groundwater, yields were maintained in the absence of irrigation, as capillary rise was able to meet most of the ET needs. With deep groundwater tables, net irrigation needs were 167 mm (2 irrigations) in a typical ‘wet rainfall year”, 246 mm (3 irrigations) in a typical “average rainfall year”, and 395 mm (4-5 irrigations) in a typical “dry rainfall year”. Simulations showed that, on typical freely-draining soils of the Yellow River basin, aerobic rice yields with HD297 can reach 6 t ha^{-1}, with 477 mm rainfall and 112-320 mm irrigation water. This is an enormous reduction from the 1000 mm of irrigation water used to produce continuously flooded rice.

At Delhi, India, aerobic rice in field experiments yielded more than 4 t ha^{-1} when irrigated at 40 kPa soil water tension in the root zone. Compared with typical amounts of water applied to lowland rice fields (under alternate wetting and drying), the amounts applied in the aerobic rice experiments of 780-1324 mm (irrigation plus effective rainfall) translated into 30-40% water savings for production levels of 4-4.5 t ha^{-1}.

Using a combination of field experiments, monitoring in farmers’ fields, and crop growth simulation modeling, Project PN16 confirmed that aerobic rice yields of 4-6 t/ha are obtainable in areas located at the margins of major rice-growing regions in the Yellow river basin. These “marginal” areas have normally been considered inappropriate for rice. The yield levels mentioned above were achieved with only 2-3 supplemental irrigations (150-225 mm), along with moderate levels of rainfall (115-670 mm per season) in areas with deep water tables (>2m). In comparison, traditional puddled, transplanted, continuously flooded (“lowland”) rice produces 6-9 t/ha but uses much more water (total 900-1300 mm), even in the presence of very shallow water tables (<0.2 m). Irrigation water productivity is much higher for aerobic rice than lowland rice.

In the Philippines, maximum experimental yields of variety Apo in the dry season ranged from 2.9 to 3.8 t ha^{-1}, with the exception of 1 site/year when yields went up to 5.4-6.1 t ha^{-1}. There was hardly any effect of irrigation water application rate because at most sites, shallow perched water tables developed during the experiments, keeping soil water tension in the root zone within 0-30 kPa. Therefore, high yields were realized with as little as 274-590 mm total water input.

From the farmers’ viewpoint, aerobic practices may be the only possible way to grow rice when water becomes scarce. In water-short but flood-prone areas, such as are found in parts of northern China, the substitution of aerobic rice for maize or cotton can substantially reduce the risk of crop loss from flooding. From the viewpoint of the whole river basin, aerobic rice practices may help maintain food security under conditions of water scarcity. And if adopted over very large areas, it may also be a means of freeing up substantial amounts of irrigation water for alternative downstream uses. However, the net impact of widespread adoption on basin-level water productivity and downstream water availability needs to be examined carefully. Much of the irrigation water that is “saved” might merely have drained back to the groundwater table, and then recycled through further pumping. This does not represent a water saving at the system scale (although it may represent an energy saving).

Extrapolation domain and scenario analysis by the CPWF BFP Impact Study suggest that aerobic rice can have large impacts in India and countries in the lower parts of the Mekong Basin, especially Thailand. These impacts included increased yields in rainfed areas, increased production and reduced prices. The IMPACT-WATER model found that India will be a net importer of rice in 2050, but that adoption of aerobic rice would reduce the amount of required imports.

Use of aerobic rice culture can also benefit other crops in the production system. There are vast areas in the Yellow and Indus-Ganges basins where rice is grown in rotation with wheat. Because aerobic rice production systems do not require puddling, they provide more favorable conditions for wheat establishment after rice harvest. They also create the possibility of incorporating conservation agriculture practices (zero or minimum tillage, residue retention) into the total crop production system.

The work of PN16 has inspired non-project partners, especially in the Philippines, to conduct research on aerobic rice management practices. This work has resulted in initial technology guidelines for aerobic rice production in China and the Philippines (wet season). These guidelines have also been incorporated in a draft manual on water management for rice in general, targeted at NARES partners and extension workers.

The sustainability of aerobic rice
PN16 began to explore possible threats to the long-term sustainability of aerobic rice systems. The development of aerobic rice systems for tropical and sub-tropical systems is at a much earlier stage than for temperate systems and unknown threats to sustainability may exist. In a long-term trial at IRRI, for example, yield of Apo under continuous aerobic conditions declined (relative to flooded conditions) during the first 10 crops. The mechanisms behind this are not yet understood. The decline was reversed by crop rotation, fallowing and flooding, but not by application of micronutrients. Two cases of immediate yield collapse were also encountered in the Philippines, in fields sown to aerobic rice for the very first time. Detailed studies are being conducted to ascertain the reasons for this, including research on micronutrient availability, soil pathogens and pH effects of fertilizers. Nematodes were always found when yield failures were observed, sometimes aggravated by the presence of root aphids, fungi, and/or nutrient disorders.

POLICIES AND INSTITUTIONS
Research results from PN16 and allied efforts have begun to inform research priority-setting in several countries. The Chinese government, for example, is providing additional funding support for aerobic rice research and development. In the Philippines, the National Irrigation Administration (NIA) and PhilRice (CPWF project partners) have included training on aerobic rice in their capacity-building curricula for farmers and extension officers. Various other non-project partners are picking up the development of aerobic rice technology including the Philippines Bureau of Soil and Water Management and Central Luzon State University. It is too early, however, for the potential water-saving capability of aerobic rice technology to have entered into broader policy debates.

The project concluded that aerobic rice technology is sufficiently mature to warrant dissemination in the Yellow River Basin, but not in sub-tropical and tropical Asia, where more research is needed to create high-yielding, sustainable aerobic rice systems.

Reflections and observations

There are a number of opportunities where the CPWF might be able to further improve coherence, increase research efficiency, and accelerate progress towards achieving development goals. These including encouraging cross-project learning, strengthening agroecological zoning and site similarity analysis for scaling out, and examining the basin-level consequences of farm-level interventions.

Building on what is known: Questions of soil fertility management, soil water management, water harvesting, and reduced tillage have been of high priority in semi-arid sub-Saharan Africa for several decades. Enormous investments in research and development have been made in these topics over many years by the Rockefeller Foundation, DFID, GTZ, IFAD and other agencies. Some of these funds have supported long-standing and highly-effective networks, among them the Soil Fertility Network for Southern Africa and the African Conservation Tillage network. CPWF Theme 1 projects in dryland areas might benefit by drawing more systematically on the accumulated knowledge and understanding of how particular technologies perform under different conditions in these environments. Project PN17 has shown the way.

Information-sharing across projects: Within sub-Saharan Africa, Theme 1 manages four projects working on questions of poverty, food security, vulnerability, drought stress, and water productivity in dryland environments. These projects are examining similar technical and institutional interventions within comparable (though not identical) climatic and socio-economic environments. Increased communication and information-sharing across these projects might accelerate the development and testing of more suitable technologies for larger areas. The same can be said for the four Africa projects and the two parallel projects working outside of Africa.

Downstream consequences of farm-level interventions: With few exceptions, Theme 1 projects take little account of the possible downstream and cross-scale consequences of field-level interventions. Improved integration with Basin Focal Projects seems desirable.

Anticipating social and economic consequences of technical change: It would seem fair to ask Theme 1 projects the following question: “If your project is entirely successful in developing and fostering widespread adoption of new technologies, policies and institutions to improve crop water productivity, how far does this take you towards meeting developmental goals?” To what extent does success in improving crop water productivity help solve problems of poverty and food insecurity? Integration of effort with Theme 2, and/ or with Basin Focal Projects, might help provide answers.

Sustainability of institutional innovations: Several Theme 1 projects aim to foster the development of local institutions for seed multiplication and dissemination. In doing so, these projects might wish to examine lessons learned by others who have taken this path. New, community-level institutions for seed multiplication typically are difficult to sustain.

Scaling out and conditional extrapolation domains: Some reporting from Theme 1 projects lacks specificity regarding the conditions that govern the performance of different technologies. Proper information management would allow projects to describe more systematically the agroclimatic and socioeconomic conditions that favor farmer adoption of a particular practice. PN16 has made substantial progress in mapping extrapolation domains for aerobic rice in Asia. Other projects have invested in spatial analysis for technology targeting, but this needs to be systematized and harnessed for widespread dissemination.

Fostering complex adaptive innovation systems: Theme 1 projects conduct researcher-managed research, participatory assessment, and simulation modeling on new crop and resource management practices. In fact, there is no shortage of prototype technologies. The challenge is to facilitate the creation of dynamic innovation systems for tailoring prototypes to local environmental and socio-economic circumstances. Innovation systems are an organic, dynamic, self-directed social process, a co-evolution of interventions and stakeholders. Integration of Theme 1 effort with other themes might be needed in facilitating and encouraging the development of innovation systems.

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. [Because water flows downstream] 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

. . . 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 . . .

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 . . .

CPWF synthesis report 2005

Goal and objectives

CPWF Theme 2 is concerned with water, poverty and risk in upper catchments. Taken together, Theme 2 projects and activities share the common goal of "Improving sustainable livelihoods for people who live both in upper catchments and downstream, through improvements in water management at multiple scales". Participants and partners in Theme 2 seek to reach this goal by realizing three objectives: (CPWF MTP 2006-08).

Understanding water and poverty in upper catchments: "This [objective] generates knowledge of the significance of water to the rural poor in upland catchments, determines the impacts of water management, and identifies new opportunities. It identifies the demand for and constraints on investment in water management and other related technologies, [and] develops appropriate solutions and adapted responses to alleviate constraints through a combination of technical and institutional changes."

Understanding biophysical and social processes in catchments: "The outcomes of catchment management are jointly determined by the interactions of social and biophysical processes. Such processes are scale and site specific. However, basic principles will be identified and models and methodologies produced . . ."

Enabling change: "This [objective] tests social learning and organizational processes that allow people to derive benefits from water and reduce the risk of human-induced hazards. It [fosters] processes of participatory action research [to modify] institutions that mediate upstream and downstream relations . . . so that the most vulnerable and poorest communities are able to derive more benefits from water."

Understanding water and poverty in upper catchments

Some Theme 2 work can be described as finding ways to reduce poverty in catchments through improvements in water productivity. To do this successfully, it is helpful to have a good understanding of the role and importance of water in the livelihoods of the poor. As it happens, connections between water and poverty can be subtle and complex and are often poorly understood. Sometimes poverty can be reduced by improving access to water, or by improving the productivity with which water is used. Other times, however, the real opportunities to reduce poverty lie elsewhere. Sometimes, effective poverty reduction strategies may actually result in water degradation, with trade-offs between peoples' livelihoods and environmental conservation.

It is especially important to understand the role of water in livelihoods of the poor when:

- Designing water management interventions aimed at reducing poverty

- Designing poverty reduction strategies that take account of consequences for downstream water management and availability

- Challenging the introduction of water management and/ or resource conservation strategies that unintentionally penalize the poor

IMPROVING ACCESS TO WATER

There is ample evidence that diversification of livelihood strategies at the household scale can reduce poverty by increasing opportunities and reducing risk. Often such diversification depends on reliable access to water resources. When water is available, farm families can undertake a variety of productive activities, some of them going well beyond conventional irrigated agriculture. These include livestock watering, dairy production, brick-making, beer brewing, gardening, and orchard plantations.

The importance of access to water was vividly illustrated for the Limpopo basin by project 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"). In a study of drip irrigation kits in Zimbabwe, project researchers found that use of drip kits can reduce by up to 50% the need for irrigation water. Farmers with water can utilize drip kits to increase irrigated area and income from irrigated agriculture. Unfortunately, many of the poorest farmers have no water resources of their own – they share them with other irrigators and with other, higher priority uses such as livestock watering and domestic use. It became apparent that offering drip kits to the poor can be unsuitable unless access to water is also improved. Based in this finding, a protocol for sustainable drip kit distribution has been developed and adopted by a number of the relevant NGOs in Zimbabwe.

As a follow-up to the above, PN17 continues to seek ways to increase water availability for the poor. Project researchers have discovered that there is, in fact, potential for groundwater development. In the driest parts of the Limpopo Basin, alluvial aquifer systems have been located that can provide safe and reliable water storage for domestic and agricultural use.

During the course of 2007, smallholder farmers in one location were trained and supported to access water from alluvial aquifers for horticulture production. The production system involves drawing water from the riverbed using simple pumps. PN17 provides additional technical support on production practices, facilitates farmer exchange visits, and fosters contacts between farmer groups and urban supermarkets. This work brings together primary hydrogeological research, capacity building through student training, capacity building of farmers in horticultural production from alluvial aquifers and linking farmers to markets. It represents both an interesting area of hydrogeological science and a very practical manner of improving rural livelihoods.
The project also found that most small dams in the Limpopo are under-utilized and/ or highly silted up and that interventions to reduce silt inflow or to de-silt dams will reduce evaporative losses (shallower dams lose a greater proportion of their stored water to evaporation). Doing so can potentially have a major impact on the livelihoods of the poor by allowing an expansion of irrigated agriculture.

It is possible to improve peoples' access to rainwater by reducing evaporation and run-off, thereby conserving water for productive use. Project PN17 has confirmed that several soil-water management practices developed and promoted for the semi-arid areas of Zimbabwe can be effective. Practices that were evaluated include deep winter plowing, no till tied ridges, modified tied ridges, clean and mulch ripping, and planting basins. Data compiled from trials conducted over many years show that mulch ripping and other minimum tillage practices consistently increase soil water content, improve crop yields, and reduce soil loss, when compared to traditional spring plowing. Further examples of improved rainwater productivity were given in the section on Theme 1.

MULTIPLE USE SYSTEMS (MUS)

One innovative way to improve water management in ways that can benefit the poor is the introduction of systems designed to support multiple uses. One Theme 2 project, PN28 ("Models for Implementing Multiple-Use Water Supply Systems for Enhanced Land and Water Productivity, Rural Livelihoods and Gender Equity") is entirely devoted to this topic. As noted in the 2005 synthesis,

"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 . . . 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."

During 2006 an "MUS review and planning workshop" finalized an agreed generic framework for designing, implementing and up-scaling MUS systems. This framework has been adopted for use in five basins. Learning alliances dedicated to MUS are active in Bolivia (community and intermediate levels); Colombia (intermediate); Ethiopia (through CRS and its partners); Nepal (community, intermediate and national levels); India (community level); South Africa (community, intermediate, and national levels); Thailand (community, intermediate, and national) and Zimbabwe (intermediate and national). Project PN28 is also doing advocacy work with environmental and water ministries. Along with local communities and other participants in local watershed planning, these ministries typically have a say in the design and replication of water supply systems. It is therefore important that they fully understand the potential benefits of MUS.

PAYMENT FOR WATER CONSERVATION AND ENVIRONMENTAL SERVICES

Water management interventions can help reduce poverty by improving the access of poor people to water resources, by improving the productivity with which they use water – or, less conventionally, by providing them with financial compensation for increasing the quantity and enhancing the quality of water available for downstream communities. This latter option – payment for environmental services or PES – is the focus of project PN22 ("Payment for Environmental Services as a Mechanism for Promoting Rural Development in the Upper Watersheds of the Tropics").

This project asks the following questions:

- How can sources of negative externalities (location and magnitude) be identified?
- How can priority areas be selected within a watershed that have a high potential to modify negative externalities and produce downstream social benefits?
- How can social benefits of farm-level interventions be measured at watershed and basin scales of analysis?
- What are important trade-offs among rural income, environmental externalities and employment generation that are generated by alternative land use strategies?
- What criteria should be used to disburse PES credits in order to achieve expected environmental and socio-economic impacts?
- How can PES systems achieve political and institutional sustainability?

What PN22 is doing to answer such questions is discussed in a later section.

LIMITS TO POVERTY REDUCTION THROUGH WATER MANAGEMENT

Protecting and strengthening poor households' access to water is important. Nonetheless, access alone is often not sufficient. Even in rural areas, income diversification through non-agricultural or off-farm employment is frequently the main pathway out of poverty. Participatory analyses from Kenya, Colombia, Bolivia and Peru by projects PN20 ("Sustaining Inclusive Collective Action That Links across Economic and Ecological Scales in Upper Watersheds (SCALES)") and PN22 found that issues of water and water access were often not the most critical factors determining household welfare.

When employment opportunities for the poor are concentrated in activities that also tend to cause environmental damage, trade-offs appear between poverty and the environment. Assessing these trade-offs may require analysis at multiple scales. Water management, especially at community and catchment scale, is relevant to the livelihoods of the poor, but the relationships can be subtle and indirect. Participatory methods such as those used by PN20 and PN22 are cost effective way of detecting these complex relationships. Project PN24 ("Strengthening Livelihood Resilience in Upper Catchments of Dry Areas by Integrated Natural Resources Management") plans to go a step further to quantify and assign an economic value to the direct and indirect impact of water management on poverty using a social accounting matrix developed for the Karkheh basin.

These findings were reinforced by BFP research results. BFP teams found that links among water, food security and poverty are best understood in an historical perspective. In basins studied by BFPs, rural societies are undergoing major transformations in which water and agriculture do not always play central roles. In the Karkheh Basin, for example, poverty rates have declined, largely because of rural to urban migration and broader national strategies to reduce poverty. In the São Francisco Basin, poverty rates have also declined. Here, however, water and agriculture do appear to play an important role.

There has been a strong out-migration of smallholder farm families, some to urban areas but others to seek jobs in large commercial farms that increasingly are specializing in high-value irrigated crops for export.
In the Mekong Basin, the shape of rural transformation varies by country and in some instances within countries. In Northeast Thailand, poverty rates are declining as people take advantage of income-earning opportunities in rapidly growing urban centers such as Bangkok and agriculture is becoming less important in livelihood strategies. In contrast, water and agriculture remain very important for poor farmers in the hillsides of Laos, or for fisher families near the Tonle Sap in Cambodia.
In the Volta Basin, the transformation of rural society is proceeding more slowly. Farming and livestock herding remain fundamental to the livelihoods of the rural poor, and water scarcity and food security are closely linked.

Rural to urban migration is important, but does not yet offer a major route out of poverty. Past success in increasing food production has come more from area expansion than yield increase, and there are concerns about how to meet future food demands for a growing population.

Understanding biophysical and social processes in catchments

Upstream land and water management affects the quantity and quality of water available to people downstream. These upstream – downstream links are the basis for watershed management programs and for programs featuring payment for environmental services. In order for them to be efficient, effective and equitable, these programs must be designed in ways that take account of fundamental relationships between land use and hydrology. They must be able to anticipate the likely magnitude and distribution of the economic and social benefits and costs associated with alternative land use strategies. They must have the capacity to conduct a rigorous scientific assessment of the potential for agricultural land use changes to enhance ecosystem services and contribute to sustainable rural development. Such capacity is lacking in many PES schemes. Theme 2 is working to change this through a combination of research and capacity building.

UNDERSTANDING CATCHMENT HYDROLOGY AND THE IMPACTS OF LAND USE

Through Theme 2 research, a better understanding is emerging of the links between land use and hydrology. In one example, researchers in the Limpopo basin working in project PN17 assessed land use changes and their effects on water resources in the Insiza sub-catchment in Zimbabwe. Using 35 years of discharge data, flow duration curves (FDCs), maximum flows, number of days with zero flows and runoff coefficients were analyzed. Landsat images were processed to examine changes over a ten year time period (1990-2000) in population density in communal areas, land use, and dam management. The study found that, because of changes in rainfall patterns, flows at the sub-catchment scale (2,260 km2) decreased from the 1960s to the 1990s. At the meso-scale (400 km2) runoff was found to have increased from 2% to over 6% over the same time period. This was attributed to agricultural intensification and changes in dam management.

Relationships between land use and hydrology are also being studied in the Andes by project PN22. This project uses the concept of the Hydrological Response Units (HRU) – defined as the minimum hierarchical level required to integrate hydrological dynamics and performance of production systems. They are, in essence, spatial units with similar climatic characteristics, soils, land cover and topographic conditions.
In delineating HRUs, hydrological, edaphic, topographic and climatic data were combined with production system data. Project researchers have been able to quantify for each HRU such variables as the levels of sediment yield, water yield and N and P deposited in downstream lakes. They have been able to identify the location and magnitude of negative externalities, and often who is causing them. This work is progressing in five sites: Fuquene (Colombia), Ambato (Ecuador), Tunari (Bolivia), Altomayo and Jequetepeque (Peru).

With the HRU structure in place, researchers developed and applied a model for ex-ante evaluation of alternative land use. This model, called ECOSAUT, allows users to quantify and value the economic, social and environmental impacts of land use changes at the watershed scale – including trade-offs among rural income, environmental

externalities and employment generation. It does this by identifying HRUs that respond uniformly to land use change. HRUs are then ranked in terms of their contribution to environmental externalities, which allows identification of priority areas for intervention (i.e., maximum impact with minimum area affected). Potential land uses are analyzed in terms of their impact on agricultural production, farm income, labor use, and catchment hydrology. Results allow decision makers to see the tradeoffs between social, economic and environmental outcomes associated with a given land use change.
This approach has resulted in a greater appreciation of the potential for conservation agriculture and agroforestry systems to reduce negative externalities. When farm-level, near-term benefits to farmers are high, spontaneous adoption can be anticipated. In other cases, however, the importance of social and environmental benefits might justify providing farmers with incentives to adopt – payment for environmental services.

UNDERSTANDING HYDROLOGY AND LAND USE AT THE WHOLE BASIN LEVEL

BFPs used simple water accounting methods to provide a more systematic look at hydrology and land use at the whole basin level. Rainfall, water availability, population density and irrigation infrastructure all were found to influence water use. In several basins with low population densities, such as the São Francisco or the Volta, grasslands and woodlands are major users of water. The large proportion of water used for irrigated agriculture in Asia (especially the Ganges, Indus and Karkheh) contrasts sharply with the very low proportion of water used for this purpose in Africa. Finally, it was noted that the proportion of water discharged from the basin into the sea is higher in wet basins than in dry basins, for example 37% for the Mekong and 28% for the Ganges vs. 2% for the Karkheh and 4% for the Limpopo (Harrington et al 2008, drawing on data from Mac Kirby, CSIRO).

The Yellow, Limpopo and lower Nile basins are said to be experiencing physical water scarcity, defined as more than 75% of the flow being allocated to agricultural, industrial or domestic uses. The Yellow River has an especially high level of water stress, with only moderate levels of renewable water present, low per capita water availability, numerous dams, and physical water scarcity and – on occasions – a zero level of discharge to the sea. In contrast, the São Francisco is said to experience little or no water scarcity.

One BFP finding is of particular interest – in many dry basins, such as the Volta or Limpopo, average annual rainfall is adequate to support high crop yields. Moreover, runoff was found to be remarkably low. This supports the contention that water harvesting (to overcome the spatial and temporal variability of rainfall) can in these areas contribute substantially to higher yields, with minimum effects on downstream users.

UNDERSTANDING CATCHMENT HYDROLOGY AND CLIMATE CHANGE

A statistical analysis was conducted by project PN17 of 50 years of precipitation, temperature and runoff data from locations in the Mzingwane catchment of the Limpopo basin. The result shows declines across the catchment in precipitation, and increases in maximum and minimum temperatures. Observed trends are compatible with those predicted by global circulation models (GCMs), as described in the Intergovernmental Panel on Climate Change Special Report on Emission Scenarios (IPCC SRES).

The trends observed have disturbing implications. Zimbabwe's second largest city, Bulawayo, obtains water from the Upper Mzingwane sub-catchment. The long-term reliability of this supply appears to be threatened. Moreover, most people in the catchment are smallholder farmers, dependant on rainfed agriculture. Reduced and erratic precipitation threatens their food security. The sustainability of rural livelihoods and urban water supplies may require an integrated strategy that includes water demand management in urban centers, investment in soil water conservation for smallholder farmers, expansion of recycling by large water users, and development of alternative employment and livelihood opportunities.

Enabling change – Social learning and institutional innovations

It was stated earlier that a good understanding of the role of water in the livelihoods of the poor is needed when designing poverty-reducing water management interventions. At some point, it becomes useful to shift emphasis from the former (achieving improved understanding) to the latter (using this new understanding in the design and implementation of action programs for change). In the context of Theme 2, action programs tend to feature social learning and institutional innovations. These are what create incentives for field-level change in agricultural and water management practices by farmers and other stakeholders.

PILOT PES SCHEMES

As described above, project PN22, working in the Andes basins, is using a simulation model to quantify the economic, social and environmental impacts of land use changes at the watershed scale. Impacts being studied include trade-offs among rural income, environmental externalities and employment generation. One set of land use practices that emerged as having the potential to reduce negative externalities were conservation agriculture and agroforestry. Pilot PES schemes were introduced in several countries to take advantage of these opportunities.

In Fuquene (Colombia), a low interest credit fund was established (using government and development assistance resources) to compensate farmers for some of the initial costs of adopting conservation agriculture. Eligible practices were those with proven social and environmental benefits. In this scheme, credit is being administered via farmers associations. Association members tend to be better-off farmers, but project staff negotiated with associations and convinced them to represent non-member small farmers as well. Financial and operational sustainability of this scheme was enhanced be increasing interest rates by 0.5% to cover costs of technical assistance. Farmers' associations have since accepted responsibility for fund management. An audit confirmed that 100% of capital disbursed in the first round of loans was recovered.

A similar scheme is being developed in Altomayo (Peru). Here the main interest is in replacing maize – pasture systems with agroforestry systems (including shaded coffee) in catchments supplying water to Moyobamba city. Inspired by results from ex-ante evaluation of land use scenarios using ECOSAUT, a committee was created in Moyobamba to organize the functioning and management of a PES fund. Represented on the committee are the Regional government of San Martin, the municipalities of Moyobamba and Nueva Cajamarca, irrigation district representatives, farmer group and religious group representatives, and the local water supply company.
In 2007, the process started by the project has empowered local stakeholders to continue promoting the use of PES. They have obtained authorization to increase water charges which will be used to finance the PES. The detailed PES scheme is now under design.

The approach is now being scaled out to new locations:

- Hydrological modeling of the Magdalena River watershed in Colombia, with support by CORMAGDALENA [sic]

- Hydrological modeling of the Las Ceibas River watershed in Colombia, with support from CAM (an environmental authority)

- Analysis of the Paute River watershed in Ecuador, with support from GTZ and the Fundación Cordillera Tropical.

- A course was given to CIPAV (a local NGO) and the University of the Andes in Colombia, who are involved in a CIFOR PES project.

- The results in the Jequetepeque watershed (Peru) are used by a PES project of WWF IIED and CARE. The same methods were used for La Gallega watershed in Piura (Peru), a pilot site of this WWF-CARE-IIED project

FEASIBILITY AND SUSTAINABILITY OF PES

Despite the positive advances described above, questions still remain about the feasibility and sustainability of widespread scaling out of PES approaches. First, to what extent to PES schemes reward farmers for bad farming practices? Farmers who invested in conservation agriculture before PES schemes are launched get no reward. Farmers who neglected to make such investments may receive payments to adopt farming practices already being used by their neighbors. Second, is the approach too complicated for widespread application? PN22 describes having taken the following steps in generating information needed to design a PES scheme. It seems to be a rather arduous process.

- Measurement and valuation of environmental externalities in the five study sites

- Identification of promising land use scenarios that could improve rural income and the provision of environmental services

- Identification of areas into the studied watersheds that have high potential of impact on environmental externalities

- Calculation of opportunity cost required in environmental services negotiation between users and providers

- Pilot implementation of the selected alternatives (e.g. farming conservation practices) to detect potential constraints of massive implementation and verify the achievement of the expected impact

- Verification of the impact of selected alternatives measuring in the field soil physical characteristics that are related with hydrological externalities (e.g. Soil shear strength, penetrability)

- Identification of poverty levels in the studied watersheds and the relation with water resources, in order to explore the impact that eventual schemes of payment for environmental services might have on communities well being.

- Quantification of other ecosystem services associated to conservation agriculture (i.e. soil carbon sequestration)

- Discussion with different stakeholders about the feasibility and convenience of creating PES schemes (i.e. Tunari watersheds in Cochabamba, Bolivia)

USING WATERSHED GAMES TO FOSTER COLLECTIVE ACTION

Payment for environmental services is one way to internalize externalities in watersheds. There are other ways, however, that rely less on financial incentives and more on collective action, negotiation, or policy change. Collective action is of special interest to Theme 2 researchers working in project PN20. These researchers seek to identify factors that favor the growth of collective action institutions, especially those that span social or ecological scales. In doing so, they use methods drawn from "experimental economics", a gaming approach to simulating realistic situations in which an individual's decisions affect not only his or her own payoffs, but those of other players as well. When engaged in gaming, participants face real incentives – they take decisions to allocate real resource, after which they receive real payoffs. Recently, researchers have begun to use gaming approaches to analyze determinants of collective action in developing countries among users of common property resources. PN20 uses gaming in a watershed context to examine how people cooperate in water management and how trust can be fostered between upstream and downstream water users.

In Fuquene (Colombia), project researchers used a "voluntary contribution" game, in which players start with tokens that they can either keep and cash in for money, or invest in a public good. Payoffs to investment in the public good depend on how many others also invest. Incentives are such that everyone would be better off if they all invested everything in the public good, but possibilities for free riding do exist and some players find them irresistible. In the game, as might be expected in reality, players in Fuquene generated only 70% of maximum possible benefits. In other words, public goods were under-provided. Allowing players to communicate and make mutual commitments increased this to 82%.

A variation on this is the "irrigation game". Players also must choose whether or not to invest in a public good, the difference being that benefits generated from the public investment are not divided equally. Instead, early players are allowed to take their benefit first while others must wait and make do with what is left. The idea is to simulate the relationship between upstream and downstream water users, in order to investigate how people behave when they face choices between what is personally beneficial to them and what is good for and fair to others. As expected, achieving cooperation is more difficult under this set of incentives. Communication still improves outcomes; however the threat of fines for taking more than one's "fair share" does not.

These games are useful in assessing the size of losses from failure to cooperate. By changing the rules of the game or the composition of the player groups, researcher can also see how different individual, social and institutional factors affect collective action, and therefore, gain insights into how to motivate cooperation. In addition, games stimulate interest in communities in the topics of common property and collective action. Months after games concluded, participants continued to discuss and analyze the results. The games gave solid substance to what had been vague or unvoiced perceptions.

MECHANISMS TO FOSTER DIALOGUE

A principal purpose of involving stakeholders in watershed games is to prepare them for fruitful and well-informed stakeholder dialogue: including dialogue between communities on the one hand and public institutions on the other.

During 2007, PN20 activities led to several events called "conversatorios" (dialogues or discussions). In the words of team members this led to:

". . . empowerment of community members to exert demands on the institutions that are supposed to represent them; improved linkages between upstream and downstream communities watershed leading to an integrated watershed vision; and concrete agreements by institutions involved in water and environmental issues to address community concerns . . . In Fuquene, participants included community representatives and representatives of: four municipalities, the environmental authority (CAR), the state government, the land reform and rural development ministries, the superintendent of public services, the department of health, the state attorney general, and ombudsman (defensoria del pueblo) [sic]."

Twenty-six specific agreements were signed related to: municipal environmental management plans; sanitation and aqueducts; permanent lake monitoring; protection of the páramo de Guargua, using conservation incentives; community participation in research regarding aquatic weeds; community participation in the committee on fisheries and lake environmental management. Continuing:

"In Coello, participants included environmental authorities (Cortolima and Cormagdalena), state governor's office (secretaries of agricultural, production systems, conservations, the irrigation district (USOCOELLO), three mayors offices, municipal councils of water and conservation, the land reform and rural development ministry, the ministry of agriculture and the University if Tolima. Twenty-seven agreements were reached [sic] . . . Both conversatorios were exciting events, and it was impressive to see how the community representatives were able not only to address questions to high level representatives of public institutions, but also to insist that the representatives give concrete answers. Sometimes they tried to evade, and the questioner (the community rep) had to insist, politely but firmly, that the person answer the question. The audience also participated actively when they liked or did not like the way someone responded to a question."

USING COMPANION MODELING TO FOSTER SOCIAL LEARNING

The use of gaming approaches is being taken one step further in the Mekong basin by project PN25. ("Companion Modeling for Resilient Water Management: Stakeholder's Perceptions of Water Dynamics and Collective Learning at the Catchment Scale"). This project uses what they call "companion modeling", where agent-based models are combined with participatory role-playing games. 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."

Companion modeling was developed as a participatory modeling technique to support local decision making processes providing a suite of models that would allow stakeholders to work together with researchers to identify and analyze the implications of land and water use scenarios. The methodology is being tested and adapted in PN25 as part of action research with communities in the Mekong designed to help communities manage their water resources more equitably and sustainability and at the same time help researcher understand more about how individuals and communities make decisions about water management.

PN25 conducted a companion modeling exercise in a watershed in northern Thailand where unequal access to irrigation water was a pressing issue. Modeling allowed stakeholders to examine different water management options proposed by different stakeholder groups. A representative of a government agency suggested building a large reservoir above the village. Other participants pointed out that this would benefit relatively few farmers. A community leader suggested constructing a series of small weirs, with water shared within small user groups of three or four households. This was more generally acceptable, despite some disagreement from participants whose plots were located outside the range of the weirs. It was decided to examine the proposal more closely by subjecting it to gaming.

Two small weirs were added across the two creeks of the gaming board. The government representative suggested that the resulting water should be allocated proportionally to farm size, a water-sharing rule favoring well-off farmers. At first, this suggestion was not contested. In later gaming sessions, villagers decided to see what would happen if a different water-sharing rule were used, one in which the same amount of water were allocated to each beneficiary of the weir, with the possibility of temporarily loaning water rights to other members in case of excess.

The modeled outcome was highly attractive.
At a later date, when an opportunity arose to invest public funds in irrigation infrastructure, community members agreed to propose the more generally attractive option. Modeling and gaming had allowed them to understand the huge difference in benefits (and benefit distribution) associated with different water management options.

Enabling change – Policies to foster integration across scales and sectors

The kinds of action research described above can stimulate processes of change that spread beyond the initial sites. Achieving widespread impact, however, typically requires creating a policy environment that supports rather than blocks collective learning and change across sectors and scales.

Watershed management often involves many government departments. The policies of these departments are not always consistent or complementary. In India and Nepal, Project PN23 ("Linking Community-Based Water and Forest Management for Sustainable Livelihoods of the Poor in Fragile Upper Catchments of the Indo-Gangetic Basin") has identified opportunities to facilitate better integration of natural resource management practices among forest and water users in upper catchments, through a better integration of forest policies and water policies. In 2007, the PN23 team concluded that the inhabitants of the upper catchment communities being studied were shifting from agricultural to off-farm livelihood strategies, thereby undermining the basis for community forest management. Community groups have been encouraged to form "platforms" for continued community resource management.

Fostering inter-communication and information sharing across sectors (e.g., forests vs. water) is important. For widespread impact to be achieved, however, it is equally important that information be shared across scales. Regarding MUS, for example, activities at the national scale (e.g., harmonizing policies across domestic and productive water sectors) and regional scale (e.g., investment in water infrastructure) should not become obstacles to local-scale creativity in designing and operating MUS systems. PN28 partners and stakeholders are working on models for achieving this in practice.

Reflections and observations

Central to the work of Theme 2 is the conviction that a good understanding of the role of water in the livelihoods of the poor is needed: (1) when designing poverty-reducing water management interventions; (2) when shaping poverty reduction strategies that take account of water-related consequences; and (3) when critically assessing resource conservation strategies that may penalize the poor. The value of "improved understanding" is greatly increased, of course, when put to practical use in the design and operation of action programs for change. Doing so may require expanded links between the work of Theme 2 and other CPWF themes, and with BFPs.

Downstream consequences of farm-level interventions: One of Theme 2's three objectives is to achieve a better "understanding [of] biophysical and social processes in catchments", including "understanding catchment hydrology and the impacts of land use". Several Theme 2 projects are engaged in preparing datasets and simulation models for this purpose. Other CPWF projects, however, are also working in the development of land use management options. Improved cross-theme integration could facilitate the generalized of modeling tools developed by Theme 2, thereby facilitating the assessment of downstream consequences for a far larger set of land use options..

The work of BFPs in understanding hydrology, land use, water availability, water productivity and poverty should not be overlooked. BFPs and Theme 2 should join hands in mainstreaming models and tools to evaluate the downstream and cross-scale consequences of farm-level interventions.

Catchment hydrology and climate change: A few Theme 2 activities touch on hydrology and climate change. This would seem to an area needing a coordinated effort by the CPWF. All themes can make important contributions to understanding the deleterious effects of climate change in benchmark basins on the livelihoods of the poor, and the extent to which new water-related innovations can ameliorate some of these effects.
Farm-level technical change and poverty: With regard to Theme 1, the following question was posed: "If your project is entirely successful in developing and fostering widespread adoption of new technologies, policies and institutions to improve crop water productivity, how far does this take you towards meeting developmental goals?" "To what extent does success in improving crop water productivity help solve problems of poverty and food insecurity?" Given the emphasis in Theme 2 in understanding the role of water in the livelihoods of the poor, Themes 1 and 2 might wish to join forces with Basin Focal Projects in seeking answers to such questions.

Enabling change and scaling out. The third objective of Theme 2 is to "enable change". In the context of Theme 2, this takes the form of developing institutional innovations to foster collective action and social learning in ways that help meet development goals. Institutional innovations described above include payment for environmental services, learning alliances for multiple use systems, and the use of gaming and companion modeling to "examine how people cooperate in water management and how trust can be fostered between upstream and downstream water users", to "assess. . . the size of losses from failure to cooperate" and to see how "different individual, social and institutional factors affect collective action [and to] gain insights into how to motivate cooperation".

But what about scaling out? How does one go about fostering the generalized use of these institutional innovations such that they affect large numbers of people in all benchmark basins, thereby making a perceptible contribution to achieving developmental goals? Links with BFPs, and with Theme 5 on broader policy influences might help.

Theme 3 – Aquatic ecosystems and fisheries

> Over large parts of Africa, Asia and Latin America, freshwater fisheries provide poor rural families with a high quality food, rich in the protein, minerals and unsaturated fats needed for 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 [goods and 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.
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> *CPWF synthesis report 2005*

Goal and objectives

CPWF Theme 3 is concerned with fisheries and aquatic ecosystems, their contribution to poor peoples' livelihoods, the value of the ecosystem services that they provide, and the ways in which estimates of these values are (or are not) taken into account when decisions are made regarding water use.

The value of a unit of water sold to an urban consumer is easy to estimate, as is the value of a unit of water used to irrigate crops. It is far more difficult to quantify the value of a unit of water used to provide ecosystem services, which encompass all provisioning, regulating, cultural and supporting functions of ecosystems. Just because a value is not easy to estimate, however, does not mean that it is negligible. Decision-makers ignore at their peril the value of goods and services provided by aquatic ecosystems.

Theme 3 projects and activities share the common goal of "Improving water productivity through sustainable use of aquatic ecosystems and thereby enhancing livelihood opportunities, food security, health and nutrition of the poor communities." A principal means of reaching this goal is through the development of ". . . decision support tools for planners and water managers, the application and dissemination of which, will provide quality information on the governance, value and water requirements of these ecosystems and ways to enhance their productivity." (CPWF MTP 2006-08)

Participants and partners in Theme 3 aim to reach this goal by realizing the four objectives described below. Specific research questions are posed with respect to each objective. As will be seen, there still are more questions than answers.

Policies, institutions and governance: "First and the foremost is a need for strong policies, institutions and governance arrangements . . ."

Valuation of ecosystem goods and services: "There is a strong need for the valuation of aquatic ecosystems and the tradeoffs among different water users. Such valuation will lead to achieving increased water productivity by incorporating the values of aquatic eco-systems and improving their management."

Environmental water requirements: "Research on environmental flow requirements will complement this work by generating meaningful decision support tools for the water managers to allocate water while accommodating the genuine needs of riverine ecosystems."

Improving water productivity in aquatic ecosystems: "The normal definition of water productivity as 'the quantity or value of goods produced per unit measure of water consumed' is inadequate to describe all the benefits achieved from water bodies. Appropriate new tools are necessary for defining and measuring water productivity in the context of aquatic ecosystems."

Policies, institutions and governance

In general, governance comprises the traditions, institutions and processes that determine how power is exercised, how [stakeholders] are given a voice, and how decisions are made on issues of public concern. Attributes of good governance are often said to include accountability, transparency and participation, and their key components: authority, order, capability and autonomy. It is fair to ask, of course, whether these attributes are always applicable to governance questions regarding natural resource management, regardless of country or culture.

WHAT ARE THE FACTORS THAT INFLUENCE PEOPLE'S ACCESS TO AND CONTROL OVER, AQUATIC ECOSYSTEMS AND THEIR RESOURCES?

Theme 3 seeks to identify management and governance options that foster consistency between two things: (1) people's access to and control over aquatic ecosystems, and (2) the biophysical characteristics of those systems. Such consistency is more likely to occur when the biophysical/ ecological characteristics of a resource are taken into account when designing or reforming governance systems. For instance, should decentralization of governance be the same for a floodplain fishery as for a lake fishery? Probably not. Among other things, the "best" governance systems for an aquatic resource may be influenced by the extent to which that resource is under- or over-exploited.

Theme 3 recognizes that traditional intra-sectoral fisheries management and governance, usually limited to stock assessment and yield maximization, has proven insufficient to ensure the sustainability of most fisheries. Fisheries sustainability is increasingly affected by factors outside the sector and at various spatial scales, including emerging global threats. Therefore fisheries management and governance should move beyond traditional approaches and consider the broader ecological, social, and economic context, focusing on threats to effectiveness and benefit delivery in the context of multiple uses of water.

When dealing with aquatic resources, some governance questions are fundamental. "Who gets the water"? "How is this decided"? "What are the trade-offs when water is allocated across uses and users"? These questions are by their very nature cross-sectoral. Cross-sectoral issues are important in most CPWF projects managed by Theme 3. This is regardless of whether the project begins from the perspective of production, valuation, or governance. While historical development has essentially focused on the development of agriculture, especially irrigated agriculture, improved consideration of fisheries and aquatic ecosystems at a later stage (now that its value is better recognized) inevitably requires expanding the scope of research to other users of water and also to the ecosystem. This also implies dealing with conflicts and finding ways to resolve them.

Project PN35 ("*Community-Based Fish Culture in Irrigation Systems and Seasonal Floodplains*"), working in the Indus-Ganges and Mekong basins, focuses on governance systems that are designed to more efficiently utilize aquatic resources that hitherto have been under-exploited. These governance systems are based on collective action.

In several benchmark basins, substantial areas of agricultural land in floodplains and deltaic lowlands are subjected on a regular basis to seasonal flooding which may last for several months. Some of these lands are used during the dry season for irrigated agriculture. When flooded, however, they normally cannot be used for crop production. 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, that there are untapped opportunities for using these waters to support managed aquatic production systems, e.g., by enclosing parts of flooded areas to produce a "crop" of aquatic organisms. Harnessing these opportunities, however, depends on getting governance right, in this case communal management of aquatic resources during floods, integrated with individual property rights for agriculture.

Changes in cultural arrangements are exemplified in Bangladesh and Vietnam. Here, PN35 fostered the rotation of community-based fish culture during the flooding season with individual-based rice culture during the dry season. Preliminary results show that lower costs of rice production and increased net returns can be obtained with no reduction in the fish catch. The benefits from fish culture are distributed among group members according to sharing arrangements pre-negotiated at the beginning of the season. In such cases the share of the fish catch allocated to poor landless members can be a relatively large part of their incomes, given their general lack of alternatives.

In 2007, communities continued participating in fish culture activities including fish stocking, protection of stocked fish, controlled harvesting, building of fencing (that allows wild fish to enter the fenced off area, but does not allow them to leave), and enforcement of prohibitions on illegal fishing gear. Through these interventions, productivity was further increased for stocked fish and non-stocked fish, even in areas affected by flooding. The stocking of exotic species has increased floodplain production without hampering the production of endemic species. Poor people in surrounding areas of the floodplains harvested at least 10% of the non-stocked fish for sale and for household consumption.

In supporting further progress of PN35, Theme 3 has encouraged the project to exploit the opportunities for contributing and adding value to the CPWF research agenda through: strategic focus on improving governance of the floodplain aquatic resources at multiple levels; outputs that inform and guide decision makers at those levels; emphasis on the benefits of its approach to multiple stakeholders; widening project emphasis to floodplains as a multiple water use system, and; considering the fish productive use of the system from an agro-ecological perspective, taking into account other productive uses and seasonal variation.

The project is further developing its analysis of appropriate institutional arrangements that support collective fish culture in the flood season in the variety of environmental and socio-cultural settings represented in Bangladesh, Cambodia, Vietnam, China and Mali. This implies understanding the conditions under which collective action in the context of community based aquaculture succeeds or fails.

WHAT KINDS OF GOVERNANCE SYSTEMS AND ENABLING POLICIES AND INSTITUTIONS FOSTER EQUITABLE AND SUSTAINABLE MANAGEMENT OF AQUATIC ECOSYSTEMS?

Equitable management of aquatic ecosystems is of special interest to the poor. A “state-of-the-art” review paper (Béné and Neiland 2006) commissioned by Theme 3 has set out a detailed list of research questions on governance. Answers to these questions can help improve our understanding of how different governance systems affect the poor.

One such question is as follows, “Is the existence of traditional authorities a good foundation for pro-poor (or improved) governance, and if so how can traditional leaders be incorporated as a stakeholder in such a way that new arrangements will benefit the poor and/or most marginalized sector of the population?” In other words how important is pre-existing “political architecture” in determining the extent to which the poor benefit from alternative approaches to fisheries management?

Issues of governance and policies in equitable and sustainable management of aquatic ecosystems were the subject of a discussion session at the International Forum on Water and Food (IFWF), held in Vientiane in November, 2006. Session participants concluded that “command and control management and governance will not deliver the benefits to the poor that could be achieved through appropriate participation in policy development and implementation. With such approaches must come devolved accountability”.

HOW CAN CAPACITY BE BUILT WITHIN NATIONAL AND LOCAL INSTITUTIONS TO UNDERSTAND THE LIVELIHOODS OF POOR PEOPLE AND THEIR USE OF AQUATIC ECOSYSTEMS AND TAKE ACCOUNT OF THEIR NEEDS IN POLICY DEVELOPMENT AND GOVERNANCE PROCESSES?

Theme 3 research on the inter-relationships among poverty, livelihoods, aquatic ecosystems, policy and governance has emphasized adaptive learning, partner participation, and partner capacity-building.

Project PN35, for example, has adopted an adaptive learning approach, promoting learning as an integral part of the management process. The process not only seeks to develop effective management options for meeting the needs and addressing the uncertainties of the stakeholders engaged in the activity with regard to resource management. It also aims to build the capacity of stakeholders at all levels in the management of community-based fish culture approaches. Partners are encouraged to work with stakeholders to evaluate their interventions, and identify strategies for improving previous outcomes.

Through this iterative process, stakeholders increase confidence in their capacity to identify problems and propose and test management options. This process also aims to facilitate dialogue and information exchange between community and government stakeholders to support decision-making.

Valuation of ecosystem goods and services

The Comprehensive Assessment of Water Management in Agriculture (CA) recognized that, “Fish and other living aquatic resources of inland water ecosystems provide important services that are seriously undervalued." But by how much? As long there is limited capacity to estimate the value of water used to provide ecosystem services, such uses are likely to be ignored in public debate. As the CA states, "Improving the consideration of fisheries in water management decisions requires better valuation methods [as well as] improved governance."

The key lies in whether "valuation" methods are restricted to economic and monetary considerations. This issue was addressed by one of the discussion groups at the IFWF. Their conclusion was that, "Aquatic resources are poorly valued and under-represented in broader water allocation and development policy. Tools are available and should be more widely used. The current focus on economic valuation misses the crucial role in livelihoods, biodiversity and ecosystem function."

During 2007, however, Theme 3 researchers recognized that no first call competitive grant project had an adequately clear focus on the valuation of ecosystem services. Work in this area cannot commence until 2008, when two second call projects are launched: PN69 "*Wetland valuation in China*" and PN71 '*Water allocation in the Tonle Sap*". For this reason, the scope of Theme 3 research on "valuation of ecosystem goods and services" was redefined in more general terms as "assessment of ecosystem services".

WHAT ARE THE MONETARY AND NON-MONETARY VALUES OF GOODS AND SERVICES PROVIDED BY DIFFERENT TYPES OF AQUATIC ECOSYSTEMS, AND WHAT PROPORTION OF THE HOUSEHOLD/ COMMUNITY ECONOMY DO THEY COMPRISE?

Within the CPWF portfolio, Project PN30 ("*Wetlands-Based Livelihoods in the Limpopo Basin: Balancing Social Welfare and Environmental Security*") is intended to focus on analyzing trade-offs among different uses of wetlands in dry environments. It aim 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, to help inform decisions on wetland use and conservation, in particular, the extent to which it is possible to increase the use of wetlands to support people's livelihoods without compromising environmental security.

In 2007, PN30 released the results of research on the diversity of uses of the Intunjambili wetland, and the diversity of their contribution to livelihoods (Chiputwa & Morardet). This research found that, within communities, there is a strong differentiation of households in terms of their use of and benefits from wetlands. Besides contributing to food security and income generation, wetland ecosystems provide households with goods and services that are not related to crop production (e.g. building material, medicinal plants, grazing areas). Overall the results emphasize the need for adapted and case-based measures for wetland conservation and suggest differentiated management approaches according to wetland uses and users.

PN30 identified the following kinds of households obtaining benefits from wetlands:

- Class A: These households generally have relatively few uses for wetlands, the most common being limited cropping, fuel-wood and water collection. Their wetland plots are typically located from other farm fields.

- Class B: These households use wetlands for many activities, including some that are relatively uncommon, for example, fishing, collection of craft materials and medicinal plants, and cultural uses.

- Class C: These households also a high number of wetland uses. They differ from class B by the fact that they do not collect craft materials. Their wetland plot is more likely to be distant from other farm fields.

- Class D: These households have no wetland plots, but use wetlands for livestock grazing, and collection of firewood, building materials, edible fruits and water.

- Classes E and F: These households use wetlands mainly for cropping. They are characterized by the absence or low frequency of the other most common uses of wetlands (grazing, fuel-wood and building materials collection).

The number and variety of wetland uses was found to be related to family size: families using wetlands for more diverse purposes (Classes B and C) are larger and better-off. It may be that they have more labor available to engage in activities in wetlands; alternatively, larger families may have a greater diversity of needs. Households who do not own wetland plots are more likely to have access to other sources of income. Sometimes the lack of a wetland plot is compensated by having access to an irrigated plot. Class F households appear to be more oriented towards farming activities, with few or no other sources of income, and with relatively few physical assets.

Little work was performed, however, on trade-offs between the use of wetlands to support livelihoods, and the use of wetlands to produce other ecosystem services.

Environmental water requirements

Theme 3 participants perceive as very important the issue of environmental water requirements. However, no first call competitive grant projects focus on this topic. In this context, Theme 3 conducted a brief study to highlight key issues raised by the application of environmental flows in fisheries. The interdisciplinary and inter-sectoral implications of environmental flows in fisheries were developed, drawing from case studies of irrigation impacts on fisheries in Lao PDR and Sri Lanka. The Theme Leader presented the results at the 10th International River Symposium and International Environmental Flows Conference, 3-6 September 2007. The presentation was entitled, "Irrigation Impacts on Fisheries: the Need to Extend the Environmental Flow Paradigm". This contributed to a key outcome of the conference: the "Brisbane Declaration on Environmental Flows".

Environmental flows are defined as "the quality, quantity and timing of water flows required to maintain the components, functions, processes and resilience of aquatic ecosystems which provide goods and services to people". Current environmental flow approaches focus on river discharge patterns as the key driver of aquatic ecosystem processes, and conceptualize impacts on the provision of ecosystem goods and services as resulting from impacts on ecosystem processes. Based on case studies of irrigation development and its impact on fisheries in the Lao PDR and in Sri Lanka, it was argued that in the wet tropics, 1) river flow may not be the most important physical-hydrological variable driving fisheries production, and 2) responses of fishers to environmental and livelihoods changes brought about by irrigation may strongly influence the yield, value and role of fisheries in livelihoods.

This suggests that the current environmental flow paradigm should be extended to a more holistic approach for assessing and managing the environmental impacts of water resources development. In particular, such an extended paradigm must account for the hydrology and ecology of off-river aquatic habitats, and for impacts on the provision of ecosystem goods and services that originate from resource user responses rather than hydrological-ecological processes. Theme 3 argues that the adoption of a more holistic approach to environmental flows and fisheries would have strong implications in the development of further research on environmental flows. For example, this would imply the improved consideration of 'externalities' such as land-use modifications, water resource development in the catchment area as well as potential changes in the availability and adoption of other livelihood options.

Improving water productivity in aquatic ecosystems

Within the CPWF, the concept of water productivity – defined as the amount or value of output per unit of water depleted – plays a fundamental role. Estimating crop water productivity is relatively uncomplicated: it is the amount or value of crops produced per unit of water depleted, or made unavailable for re-use, e.g., through evaporation, transpiration, contamination, or flow to a saline sink. Estimating livestock water productivity more challenging.

However, the question of how one goes about estimating water productivity in fisheries and aquatic systems is infinitely more puzzling. How is water productivity best defined and measured in the context of aquatic ecosystems?

WHEN AND HOW CAN WATER PRODUCTIVITY AND LIVELIHOODS BE IMPROVED BY INTEGRATING FISH PRODUCTION AND HARVEST OF OTHER AQUATIC ANIMALS AND PLANTS INTO FARMING AND IRRIGATION/FLOOD PRONE SYSTEMS?

In the state-of-the-art review commissioned by Theme 3, there was some discussion of the productivity of aquatic resources (interpreted in terms of the productivity of fisheries in rivers, floodplains, reservoirs, and lakes) but little discussion of water productivity *per se*. Project PN35 continues to work on a conceptual framework for "aquatic ecosystem water productivity", but this work remains at a fairly rudimentary stage. The notion of water productivity applied to fisheries and aquatic ecosystems was also featured in a discussion session of the IFWF.

One project, PN34 ("*Improved Fisheries Productivity and Management in Tropical Reservoirs*"), working in the Indus-Ganges, Nile and Volta basins, focuses on fisheries in tropical reservoirs, naturally-occurring or artificially-created bodies of water fed by rivers or streams, whose primary use is to produce fish. As noted in the CPWF 2005 synthesis:

"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. [Project] 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 ar-

rangements, 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."

PN34 aims to improve fisheries productivity and management in reservoirs. In India, reservoirs are recognized as potential sources for major fisheries development that can benefit the landless community fishers in particular. Major project interventions have included: (a) enhancement through stocking of fish seed of right kind of species and size and (b) analysis of existing suggesting better institutional arrangements for fishing and marketing. The impact of these interventions led to increased fish landings by over 60% and an increased contribution of fish in commercialized food products.

During the course of 2006 and 2007, project participants engaged in socio-institutional assessments of fisher communities (data collection and analysis still continuing); surveys of the physical environment (e.g., variables affecting water quality); evaluations of biological productivity and ecosystem services (different approaches used in different basins); assessments of fish stocks (data collection in process or completed from secondary data and supplementary surveys); analysis of the potential for enhancing fish productivity; and a study of local markets to ascertain the extent to which increased fish production can serve as a source of increased cash income.

WHAT NEW TECHNOLOGIES CAN BE DESIGNED TO FURTHER IMPROVE THE INTEGRATION OF FISHERIES INTO FARMING SYSTEMS?

The Comprehensive Assessment notes that, "There are two broad challenges for fisheries production. The first is to sustain the current levels of fisheries production and other ecosystem services through the provision of target-directed environmental flows that sustain or restore the aquatic environment, including its diversity, and improved management of capture fisheries. The second is to increase current levels of fisheries production through the wider adoption of methods for enhancing and intensifying production, such as stocking and aquaculture." This clearly includes the integration of fisheries into farming systems.

The key is to have simple and rapid tools for estimating seasonal water requirements needed to sustain aquatic ecosystems, fish communities and fisheries. Once such tools are available, implications for water management technologies (e.g. sluice designs, barrages, weirs, and other in-river structures) and conservation practices (water requirements for different designs of rice ecosystems; farming practices; fish pond management regimes) become apparent. In this way, fisheries requirements can be taken into account when irrigation systems are designed or operated, and when in-river structures are built and utilized.

Several projects are contributing to the development and application of needed tools, among them PN10 and PN46 on water quality; PN46 on irrigation system design and management; and PN35 on water requirements and in-river structures.

Progress made by Project PN10 ("*Managing Water and Land Resources for Sustainable Livelihoods at the Interface between Fresh and Saline Water Environments in Vietnam and Bangladesh*") is particularly interesting. Millions of people in South and Southeast Asia are poor and food insecure because agricultural production is hindered by seawater intrusion during the dry season, when fresh water for irrigation is limited.

The rivers in the coastal deltas of Vietnam and Bangladesh are tidal. During the wet season the river water is fresh, but during the dry season, salinity increases. During the flood tide salt water flows upstream, then returns downstream during the ebb tide. The high hydraulic heads during high tides lead to salinization of the lands adjacent to the rivers. Agricultural lands are protected by levee banks and sluice gates which are closed to prevent entry of saline water during the dry season and are opened in the wet season to allow drainage from the polders. However, low availability of fresh water to grow crops during the dry season is a major limitation to food security and livelihoods, exacerbated by high levels of soil salinity prior to the onset of the main rainy season. In Bangladesh, many coastal delta agricultural lands remain barren during the dry season despite a huge investment in polders.

In such situations, interventions may include new varieties, changes in water management and irrigation practices, and new production systems.

Varieties: In both countries, new high yielding varieties with better tolerance to salinity have been introduced to project areas in coastal regions, in collaboration with PN7. Such varieties, however, must also be compatible with selected farming systems. In Vietnam, for example, rice varieties OM4498, OM4872 and MTL384 have been found attractive for "(rice/ upland crop) – rice" and "rice – (rice + fish)" systems. In contrast, the rice variety Mot Bui Do is preferred for "shrimp – (rice + fish)" systems.
In Bangladesh, the Saltol gene has been incorporated in a local high yielding variety (BRdhan2) and seed in-

crease is underway for testing at IRRI and in target sites. Some salt tolerant, short duration varieties from Vietnam are also performing well as a direct seeded, pre-rainy season crop. However, rice in the coastal salt affected regions of Bangladesh is also sometimes affected by flooding at times, hence the need for varieties with both salt and submergence tolerance (see Theme 1, PN7). Some farmers have been trained in quality seed production of modern varieties and there are plans for further training, especially of women.

LAND USE ZONING AND WATER MANAGEMENT:

In the 1990s, investments were made in the Mekong delta of Vietnam to increase rice production by the progressive introduction of sluice gates. These were intended to prevent saline water intrusion so that a dry-season rice crop could be grown after the main rainy season crop. This strategy backfired, however, in the western part of Bac Lieu province, where there is a predominance of acid sulphate soils unsuitable for rice production, and where saline water is needed for a highly profitable emerging brackish shrimp industry. In 2001, some farmers destroyed a major sluice to gain access to the saline water needed for shrimp culture.

Building on a DFID funded project that preceded it, PN10 has worked with stakeholders in Bac Lieu Province to analyze the effect of sluice gate management on water flows and quality, and to design a sluice gate management schedule acceptable to rice farmers (in the eastern part of the province) and shrimp farmers (in the western part). Research activities included intensive monitoring of water quality, refinement of the VSRAP[1] model, and analysis of scenarios with provincial water managers and authorities

The solution involved delineating land use zones with different patterns of fresh and brackish water supply. Some zones were designed to have fresh water all year round: these are suitable for rice and vegetable production. Other zones were designed to have fresh water in the wet season and brackish water in the dry season: these are suitable for rice-shrimp rotations. Still others have brackish water all year round: these are suitable for shrimp and production.

CROPPING SYSTEMS AND CROP MANAGEMENT IN VIETNAM:

The project team worked with Vietnamese farmers to develop and evaluate new production technologies. Collaboration with rice farmers aimed at increasing rice yields and cropping system intensity (up to three crops of rice per year, or two rice crops and one vegetable crop), while collaboration with shrimp farmers aimed at developing more productive, profitable and resilient shrimp-based and rice-shrimp production systems. The project has found that growing rice in rotation with shrimp benefits shrimp production. It was hypothesized that this may be due to the presence of stubble. This has led to the introduction of reeds or *Scirpus littoralis* Schrab in monoculture shrimp system to benefit the shrimp – and to generate income from sales of handicraft reed baskets in the cities.

EXPANSION OF DRY SEASON RICE AREA IN BANGLADESH:

In Bangladesh, PN10 worked on ways to introduce a second rice crop after the rainy season crop in coastal areas subject to salt-water intrusion. The project has shown that river salinity increases during the dry season, reaching the maximum salinity for rice culture (~4 dS/m) by mid-February. At this stage the crop is not yet mature, and yields are poor unless supplemental irrigation is used. There is an opportunity to grow dry season (boro) rice using groundwater, and/or using the river water until mid-February and finishing the crop on (low salinity) river water stored in the natural river channels in the polders before the river water gets too saline.

In areas where suitable groundwater is not available or affordable, the amount of water which can be stored in the channels will determine the area of boro rice that can be grown. In areas where the groundwater is fresh and available, there has been rapid and intense investment in groundwater pumping. While pumping is from considerable depth (more than 100 m), the energy required is small because of the high hydrostatic pressure. An important question is the sustainability of high levels of groundwater pumping, because of the risk of salinization of the fresh aquifer from the overlying saline groundwater as pressure levels are lowered by pumping from the fresh aquifer. Preliminary assessment of pressure levels and water quality by PN10 in one small polder suggest that pressure levels recover rapidly at the end of the pumping season, and that the effect on salinity is generally small. Whether this applied in other polders is unknown.

EQUITY CONSIDERATIONS:

In both the Mekong delta of Vietnam and the Gangetic delta of Bangladesh, the introduction of brackish water shrimp production during the dry season has created economic wealth (for some) and expanded national

1 The project team added an important water quality parameter (acidity) to the VSRAP hydraulic and salinity model, and developed the BayFish-Bac Lieu model which combines outputs from the VRSAP model with expert systems (from interviewing farmers, fishers, key informers, scientists) to identify optimal water control regimes and trade-offs between water uses. The project team also applied the ORYZA2000 model to assess crop water requirements and optimize the use of scarce fresh water for rice.

export earnings. However, in Bangladesh, expanded shrimp production has been at the expense of livelihoods and food security for many small farmers and landless laborers, and has become a source of serious social tension and conflict. Here the shrimp farming industry is dominated by a few wealthy business persons from Dhaka who control vast areas of shrimp ponds (up to tens of thousands of hectares each), on land leased for the dry season from hundreds of thousands of small farmers. In contrast, in Vietnam the shrimp industry is dominated by small farmers.

Equity considerations also arose in the context of PN35 work in Bangladesh. An independent study raised the following kinds of questions – for which answers are yet to be provided:

- What are the multiple uses of water by different stakeholder groups with overlapping influence in deep water floodplain agroecosystems?

- What are the contributions of community-based fish culture in seasonal floodplains to the livelihood of different groups? How can these contributions be measured?

- How can property constraints to the development of community-based fish culture be most effectively assessed?

HOW SHOULD WATER PRODUCTIVITY BE MEASURED IN ORDER TO FACILITATE INTER-SECTORAL COMPARISONS AND SUPPORT WATER MANAGEMENT DECISIONS?

Research managed by Theme 3 has focused on increased aquatic resource productivity in a range of water bodies (lakes, rivers, floodplains, ponds). Evaluations of water productivity for these systems have not provided measures appropriate for use in making inter-sectoral comparisons or supporting water resource management decisions. These experiences generally reflect the difficulty in interpreting the concept of water productivity in a field that has traditionally focused its assessment on the level of output (principally fish) without much consideration of other ecosystems services.

The Theme 3 objective to quantify “water productivity of fisheries” *per se* proved to be of limited practical applicability. Ultimately, it was seen as an attempt to satisfy an objective set by scientists rather than an objective prioritized through stakeholder discussion for developmental purposes. In practice there has been a tendency to re-state the objective in terms of simply increasing the productivity of fisheries. This is reflected in the CPWF Medium-Term Plan and in work plans for relevant projects (PN34 and 35).

Theme 3 initiated a study aimed at clarifying the conditions under which the concept of water productivity might be most suitable applied to fisheries and aquaculture. In general it was concluded that the water productivity concept may be relevant in confined water bodies with clear delimitations of boundaries, where water is a limiting factor.

It is critical that the water productivity concept be revised and further developed to better reflect the social and ecological dimensions of water use for fisheries. The concept should be used along with a range of assessment and valuation tools in order to provide a comprehensive and holistic assessment of fisheries costs and benefits (including consumption, ecosystem and human health, poverty, governance arrangements) in a context of multiple uses of water. Such approach implies the evaluation of the social-ecological tradeoffs inherent in the water productivity concept, especially between increased food production, ecosystem conservation and poverty alleviation.

Failing in this, the concept may be misleading to the perception of managers and policy makers, and increased water productivity of fisheries may in turn affect aquatic ecosystems and the poor. A good illustration is provided by the auctioned village ponds of India where the great increase of water productivity through fish culture has often been at the expense of the poor (who lost access to the pond) and the environment (due to the degradation of water quality and the pond ecosystem).

Other research areas developed under Theme 3

FISHERIES AND AQUACULTURE AT THE RIVER BASIN SCALE

Diagnosis of fisheries and aquaculture at the river basin scale has been identified as a high priority area by Basin Focal Projects (BFPs). To further progress in this area, Theme 3 submitted a research proposal to the BFP. Although not approved for funding, Theme 3 and BFP Central are planning a ‘BFP-Fisheries workshop’ to be held in early 2008. This workshop will discuss a conceptual framework and research tools for aquaculture and fisheries development in line with basin priorities. It will draw attention to possible implications of not taking fisheries issues into account, and implications for food security of the rural poor dependent on aquatic resources.
With regard to livelihoods, fishing is often only one – generally seasonal – aspect within a complex and flexible livelihood strategy matrix. This justifies addressing fisheries within a framework of a multidimensional approach to poverty reduction and agricultural water use.

When dealing with livelihoods, fisheries should be recognized as one of the activities depending on and using water resources in the basin, just like rainfed cultivation, livestock rearing and irrigated cultures. Yet freshwater fisheries and aquaculture invariably take place in multiple use environments and are often considered a secondary activity, particularly in reservoirs.

Assessing and valuing aquatic production systems at the river basin scale opens a range of new research areas in fisheries science. The challenges to deliver a framework are very high and should be recognized as such. In such a context, adaptive, participatory and integrated approaches are promoted by Theme 3. This notably involves the participation of relevant stakeholders, the identification of key partners (e.g. NARS, International research organizations, etc.) and respective potential for collaboration, and the use of different sources of knowledge including scientific literature and local knowledge.

WETLAND CONSERVATION AND POVERTY ALLEVIATION

In her capacity of researcher, the Theme Leader has contributed to studies on Wetland and Poverty Alleviation, and Wetland and Agriculture interactions. The coherence and complementarity with the Theme 3 research agenda facilitated direct synergies with research conducted by CG Centers, especially IWMI and WorldFish. The IWMI study is contributing to a program led by Wetland International to address the issues of wetland conservation and poverty reduction. It also contributes to Theme 3 efforts in analyzing the complex linkages between the conservation of aquatic ecosystems and the alleviation of poverty, recognizing that these objectives are not always congruent.

An analytical framework for understanding natural resource conservation and poverty reduction relationships was developed. This proved to be very useful for identifying and analyzing complex cause-effect relationships that are often non-linear and difficult to predict. The framework also enabled the identification of trade-offs between biodiversity conservation and development. This is considered as a distinct advantage over existing frameworks which tend to view situations from either a conservation or a development perspective. The lessons and best practices selected among the case studies include: building multi-stakeholders platforms that represent all key groups including the poor, managing open-access resources use, diversifying livelihood options, promoting wetland conservation through micro-credit, and addressing potential psychological impacts of change on village communities .

Wetland and agriculture interactions

The Theme leader contributed to the GAWI (Global Agriculture and Wetland Interactions) initiative funded by the Netherlands government and led by Wageningen University in partnership with the Ramsar Convention Bureau and IWMI. The goal of the GAWI initiative is to support the development of sustainable agriculture and wetlands interactions in ways that maximize livelihood benefits while maintaining ecosystems functions.
The DPSIR (Driver, Pressure, State, Impact and Response) framework was proposed to study the complex and dynamic interactions between wetlands and agriculture. This analytical framework supported a clear conceptualization of the situation, and provided rigor and a logical progression in understanding the linkages. It also allowed comparison of a highly diverse range of case studies.
Preliminary results show that the key issue in wetland and agriculture interactions is the over-exploitation of the provisioning services at the expense of the regulatory and support services. This has implications for the medium- and long-term sustainability of the wetland agriculture and aquaculture, and for short-term impacts on other services. GAWI will thus seek to effectively manage and reduce the negative impacts associated with the provisioning use of the natural resource base of wetland ecosystems and ensure the maintenance of the regulatory and support ecosystem services.

Reflections and observations

Aquaculture and reservoirs in dryland environments. Several CPWF projects are focused on the establishment or management of ponds or small reservoirs in dryland environments. These are usually intended to have multiple uses, aquaculture among them. Theme 3, in collaboration with other themes and with BFPs, might wish to more closely examine the productivity of these reservoirs in aquaculture, the extent to which they accelerate water depletion through evaporation, how much they imp rove livelihoods and reduce poverty, and whether they cause decreased water availability for downstream communities.

Water quality and aquatic resources. Theme 3 researchers clearly place a high priority on developing methods to value ecosystem services – so that these values can be taken into account in decision-making on water allocation and use. Within this broader issue of valuing ecosystem services, there might be some merit in a much more specific focus on water quality and its effect on aquaculture and fisheries. Upstream water management, including upstream investments in water resource development and land management practices in agriculture, can have large effects on the quantity and quality of water available for fish culture. Through research on the effects of water quality change on fisheries productivity and people's livelihoods, Theme 3 could further develop its alliance with   on ways to influence upstream water and land management to benefit downstream populations.

Enabling change and scaling out. One objective of Theme 3 (and for all other themes) is to enable change. In the context of Theme 3, this includes activities aimed at fostering changes in governance and property rights to facilitate community-level collective action and investment in aquaculture.

Scaling out raises questions such as: How does one go about fostering the generalized use of such institutional innovations so that they affect large numbers of people, thereby making a perceptible contribution to achieving developmental goals? How do you go from two communities to 200,000?

Theme 4 – Integrated basin water management systems

> The focus of attention [now] 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 change . . .
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> *CPWF synthesis report 2005*

Goal and objectives

Basin ecosystems are under increasing pressure. Populations are growing, food demand is increasing, and urbanization is accelerating. Resource degradation (erosion, reduced river flows, groundwater depletion, pollution of surface and groundwater, degradation of aquatic ecosystems) proceeds apace, generating water-related externalities to the detriment of downstream communities. Technical, institutional and policy innovations are needed that address all of these issues simultaneously.

The development and use of such innovations must take account of innumerable complications, including temporal and spatial variability in water availability, risks of floods and drought, multiple uses for/ users of water, confounded water rights and water governance, and lack of resources and political will to set things right. Basin level research can help improve our understanding of the problems, issues and factors described above, and may even help identify interventions for securing equitable and sustainable increases in agricultural production, profitability and productivity.

The scope of Theme 4 allows it to help address these challenges by seeking answers to key questions, among them:

- How can basin water and land resources be managed to equitably and sustainably enhance agricultural production, profitability and productivity?
- What kinds of agricultural development strategies are most effective in reducing poverty in different parts of the basin?
- How might these strategies affect water and land resources at the basin level?
- By how much does basin-level water productivity need to increase so that adequate water is left for the environment?
- How can this level of increase be attained?

Theme 4 projects and activities share the goal of " . . . [contributing] to poverty alleviation and to enhancing food, health and environment securities through the generation of the knowledge base needed to better manage water, land and agricultural production systems in ways that lead to increasing agricultural output and water productivity in agriculture." (CPWF MTP 2006-08) Participants and partners in Theme 4 aim to reach this goal by realizing three objectives:

- Innovative technologies and management strategies developed, tested, disseminated and applied

- Effective policies and institutional arrangements identified, disseminated and applied

- Decision support tools and information developed, disseminated and utilized

Innovative technologies and management strategies

"Efforts to [increase] agricultural production and water productivity are constrained by lack of a good understanding of location specific (a) potential, attainable and actual yield; (b) technological and management practices that would enable resource poor agricultural producers tap this potential; (c) the cost and benefits of tapping such a potential and (d) implications of [tapping] the potential in one location on other agricultural producers and other water users including the ecosystem." (CPWF MTP 2006-8)

Basin-wide benefits can be enhanced by allocating labor, capital, land and water resources to suitable crop, tree, livestock and fishery production systems, while using appropriate technologies and management strategies. During the first phase of the CPWF, as has been described above, considerable research has been conducted within Themes 1, 2 and 3 to develop such technologies and strategies.
For its part, the work of Theme 4 on technologies and management strategies has focused on the following:

- Evaluating downstream, cross-scale consequences of the widespread adoption of new crop and livestock production practices, and developing ways to manage negative externalities.

- Assessing strategies to increase water availability through safe re-use of wastewater

- Taking a closer look at the special role of small reservoirs in dry environments

TECHNOLOGIES AND MANAGEMENT PRACTICES FOR ENHANCING BASIN-WIDE CROP PRODUCTION AND WATER PRODUCTIVITY

In the Volta basin, Project PN5 ("*Enhancing Rainwater and Nutrient Use Efficiency for Improved Crop Productivity, Farm Income and Rural Livelihoods in the Volta Basin*") conducts research to identify on-farm technologies and management strategies that lead to sustainable and profitable improvements in crop yields and crop water productivity. Theme 4 builds on this by focusing on the following two "value-added" questions:

- In which areas of the basin can these technologies and management practices be applied (scaling out)?

- What would be the hydrologic, social, economic and environmental impacts of basin wide application of these technologies and management practices (downstream and cross-scale consequences)?

Project PN5 is evaluating several technologies and practices, including: "Soil fertility management practices; soil and water conservation practices; diversification into tree crops; and field boundaries and wind breaks of Acacia." (From Theme 1)

At the farm-level, adoption of some of these technologies in the Volta basin are observed to have had positive localized hydrologic and ecological benefits: reduced runoff and soil loss, increased infiltration, more rapid groundwater recharge, and increased dry season flow in nearby streams. The overall hydrological impacts, however, are difficult to assess because of patchy technology adoption patterns and lack of data. Soil water balance assessment using DSSAT models indicate that some technologies reduce runoff by up to 35% and increase deep percolation by up to 25%. Increased deep percolation is expected to have a positive impact on groundwater recharge.

If the adoption of new farm-level water-saving technologies were to become truly widespread, what might be the downstream and cross-scale consequences? If in-field rainwater were widely adopted, would aggregate run-off be reduced to the point that downstream water supplies might be threatened? What about downstream water for hydropower and urban consumption? Would that be reduced?

These are serious questions. Urbanization in the Volta basin is accelerating, resulting in increases in urban water demand and electric power consumption (thereby increasing the demand for hydropower). Most towns have inadequate water and sanitation facilities. Ouagadougou with a population of 1.2 million people experiences water shortages during the dry season and, despite new dam construction that provides an additional storage capacity of 200Mm^3, water scarcity persists. There has also been some expansion in irrigated area.

Happily, there is reason to believe that the widespread upstream adoption of soil-conserving, water-harvesting practices would not threaten downstream supplies. To the extent that erosion is reduced, siltation of downstream reservoirs would also be reduced. Moreover, sub-basin water balance studies conducted by the Volta BFP have found that run-off accounts for only a small proportion (less than 5%) of rainfall received in upper catchments. Most rainfall is used for transpiration in grasslands, or is simply lost through unproductive evaporation.

BASIN-LEVEL WATER PRODUCTIVITY AND LIVESTOCK TECHNOLOGIES

Livestock production is a major component of global agriculture. Its importance is expected to continue to grow, driven by population growth, urbanization, higher incomes and changes in dietary preferences. To be sustainable, livestock production will need to address environmental concerns: over-grazing and soil erosion, water pollution, water depletion in areas where livestock are feed with irrigated grain, global warming related to methane emitted by livestock, and loss in biodiversity associated with conversion of wetlands and forests into grazing lands.

An evaluation of the performance of existing livestock production systems in developing countries indicates that there are significant opportunities to sustainably and equitably enhance the benefits, profitability and productivity of systems with livestock. One component of Project PN37 ("*Increasing Water-Use Efficiency for Food Production through Better Livestock Management in the Nile River Basin*") explores how technical interventions can, at the basin-level, enhance positive and reduce negative impacts of livestock production. This is achieved through the development of an analytical framework, and in-depth studies on livestock production in Ethiopia, Uganda and Sudan, complemented by case studies drawn other parts of the Nile basin.

The livestock water productivity framework developed by PN37 has identified pathways for enhancing livestock benefits, profitability and productivity through appropriate water, feed and livestock management. Three strategies have been identified for improving livestock water productivity:

- Better feed sourcing strategies.
- Water and land resources conserving strategies
- Enhancing benefits from livestock

BETTER FEED SOURCING STRATEGIES:

Studies carried out by PN37 researchers have shown that there are huge differences in water productivity among alternative feeds and that the amount of water used for livestock feed production can be reduced by 50%. In northern Ethiopia, it was found that drought tolerant cactus cladodes are used by the farmers for cattle feed, either alone or mixed with cereal straw. Cactus cladodes have high water content even in the dry season. Their use as feed can help reduce the frequency of livestock watering. Cactus can be easily integrated into smallholder farming system as living fences or on very marginal lands that have no other uses and thus improve feed resources, especially for critical drought periods.

The water productivity for plant dry matter varies widely. The biological maximum is estimated at about 3.33 kg/m^3 of rainwater yet actual productivity is usually very low – 0.1-1 kg/m^3 for rangelands, 0.5-2.5 kg/m^3 for improved natural pastures, and 0.5-1.7 kg/m^3 for irrigated alfalfa. Using water-efficient feed for livestock can increase overall agroecosystem water productivity.

Studies of different rainfed farming systems in Ethiopia show livestock water productivity is positively correlated with the share of animal diet composed of crop residue. In the Awash River Basin in Ethiopia, livestock water productivity increased from 0.1 to 0.6 US$/m3 as the percentage of crop residue in animal diet increased from 35 to 75%. While an increase in crop residue percentage of animal diet can reduce the water required to produce livestock feed, it may be in conflict with other traditional uses of crop residues – e.g. as mulch or fuel wood.

WATER AND LAND RESOURCES CONSERVING STRATEGIES:

Livestock affects (a) water availability by influencing the partitioning of rain water into infiltration and runoff through alteration of vegetation cover and soil compaction and (b) water quality through silt, nutrient and pathogen loading. A PN37 study has shown that in good rainfall years, cattle herd size may increase to as much as 90 per household, with about half of them dying during drought years – but that only 18 cattle per household were needed for a reasonable standard of living and that maintaining a constant herd size of 40 would reduce cattle deaths during dry years.

Applied to a larger extrapolation area of around 90,000 km^2 with approximately 1,000,000 cattle, such a strategy would reduce livestock water use by 1 billion m^3 per year and save feed to support animals during the dry years. The rainwater saved would be used to support other ecosystem services. The studies concluded that improved livestock management strategies (particularly a combination of appropriate herd size and water conserving feed sourcing strategies) have a high potential to reduce the negative impacts of livestock production on water resources and to contribute to expanded basin-wide benefits.

ENHANCING BENEFITS FROM LIVESTOCK:
Livestock provide a wide range of benefits to herders and society – meat, milk, eggs, draft animal power, and manure. They also provide alternative wealth saving strategies for the poor. Studies have shown that there are tremendous opportunities of enhancing these benefits through better herd management (species and breeds, health care and drinking water and feed availability) and value-adding through appropriate storage, processing and marketing interventions that enhance quality and increase "shelf-life" of livestock products. This is amply illustrated by households that have integrated water-livestock resources management in places with a good market access.

Around Addis Ababa, Ethiopia, there are farmers who have adopted household water harvesting systems to meet year-round domestic and livestock water needs. With a combination of improved feed resources, hybrid dairy cattle, livestock health care, and good diet and watering practices, milk production increased from less than 2 liters a day to more than 40 liters a day. The integration of dairying into this water-harvesting-based livelihood strategy increased the financial, human, social, and physical assets of poor rural households to a level exceeding that possible through crop production alone. Increased cash flow enabled more farmers to diversify their incomes and even open small shops serving the village area.

BASIN-LEVEL WATER PRODUCTIVITY AND WASTEWATER TECHNOLOGIES
One way around water scarcity is to augment water supply by fostering the safe, productive use of wastewater. Rapid urbanization is contributing to the growing competition of water among uses and to increase waste water production. In most urban centre waste water is inadequately treated and consequently pollutes surface and groundwater resources. Use of wastewater in urban and peri-urban agriculture (UPA) is increasing. For example, wastewater irrigated vegetable production around Kumasi City, Ghana, supplies about 90% of local demand for vegetables and supports the livelihoods of over 12,000 farmers. UPA can contribute to poverty alleviation through employment creation, higher incomes and lower food costs. However, waste-water based UPA can pose health and environmental problems.
Theme 4 Projects PN38 ("*Safeguarding Public Health Concerns, Livelihoods and Productivity in Wastewater Irrigated Urban and Peri-Urban Vegetable Farming in Ghana*") and PN51 ("*The impact of waste water irrigation on human health and food safety among urban communities in the Volta Basin – opportunities and risks*") built on past work aimed at understanding the nature and extent of the problem, and then finding and applying solutions in the Volta basin. This project responds to local and global demand for information. In Ghana, municipalities and the Ghana Tourism Board alike were seeking advice on how to reduce the increasing incidence of gastrointestinal disorders. At the global level, the Food and Agricultural Organization FAO and World Health Organization (WHO) were seeking credible information that could be used to develop guidelines on safe use of wastewater in situations where treatment facilities are inadequate or entirely absent.

These projects have established that vegetables generally contain high levels of faecal coliforms and helminth eggs. A total of 180 vegetable samples (lettuce, cabbage, and spring onion) were randomly collected under normal purchase conditions from nine major markets and 12 specialized selling points in three major Ghanaian cities: Accra, Kumasi and Tamale. The samples were analyzed for pesticide residue on lettuce leaves, total and fecal coliforms, and helminth egg counts. Analysis showed that pesticide residues exceeded the maximum residue limit. Chlopyrifos (Dursban) was detected on 78% of the lettuce, lindane (Gamalin 20) on 31%, endosulfan (Thiodan) on 36%, lambda-cyhalothrin (Karate) on 11%, and dichloro-diphenyl-trichloroethane on 33%. Vegetables from all three cities exceeded recommended standards of fecal coliform populations as the geometric mean values ranged from 4.0 × 103 to 9.3 × 108 g^{-1} wet weight. Lettuce, cabbage, and spring onion also carried an average of 1.1, 0.4, and 2.7 helminth (Ascaris lumbricoides, Ancylostoma duodenale, Schistosoma heamatobium, and Trichuris trichiura) eggs g^{-1}, respectively. This poses a major health risk, partly because many vegetables are consumed fresh or only slightly cooked.

Sources of contamination include soils, irrigation water, animal (poultry) manure, vegetable cleaning activities, and even display in open-air markets. Because of the multiple sources of contamination, even lettuce produced with piped water was not free from faecal coliform. The study challenges the conventional wisdom that only lettuce grown using waste water has unacceptable levels of pathogen contamination. Risk can be high regardless of water source. In spite of health hazards, urban and peri-urban agriculture will continue to expand within the limits of available land resources.
The studies established that health risks can be managed so that UPA producers can continue to use waste-water resources. They recommend the use of an

integrated approach to reducing health risk that comprises of:

- Use irrigation methods that reduce direct contact of crops with contaminated water

- Reduce soil contaminants by decreasing surface runoff inflows from areas with high levels of pollutants, and by using composted, not fresh, animal manure

- Promote the production of cooked vegetables and/or alternative crops with lower health risks.

- Build the capacity of producers to produce more safely. Increase public awareness of contamination pathways and attendant risks

- Wash vegetables with clean water before marketing

BASIN-LEVEL WATER PRODUCTIVITY AND ENSEMBLES OF SMALL RESERVOIRS

In relatively dry rainfed environments, small multi-purpose reservoirs are often an important source of water. They provide water for domestic use, livestock watering, small scale irrigation, fisheries, brick making, and largely undocumented environmental functions such as supporting wild life. When numerous small reservoirs are found in a sub-basin or basin, they can be analyzed as a single "ensemble" of reservoirs. An ensemble can store a substantial quantity of water and, in principal, have a significant effect on downstream flows. Such effects typically are poorly understood and rarely considered when additional reservoirs are built.

Within Theme 4, this topic is studied by Project PN46 ("*Planning and Evaluating Ensembles of Small, Multi-purpose Reservoirs for the Improvement of Smallholder Livelihoods and Food Security: Tools and Procedures*"), working in the Limpopo, Sao Francisco and Volta basins. Studies in these basins show that there are many competing uses of water (livestock watering, domestic use, irrigation, fishing, brick making, and collection of reeds used for roofing) and that the water productivity is use, season and location dependent. Not surprisingly, brick making had the highest water productivity, because of a high price for bricks). Livestock accounted for about 70% of consumptive water use.

Impacts of land use on reservoir water inflow and quality were evaluated. Evidence from the Mzingwane reservoir study indicates that, at this time, activities in the communal lands are not significantly impacting the ecosystem health of reservoirs, as water quality characteristics and plankton diversity on communal lands were not significantly different from the pristine reservoirs in National Park. However, water managers are urged to monitor the changes in land and water uses around these multipurpose reservoirs in order to prevent possible detrimental land and water uses that might occur in the future.

The performance and profitability of two small reservoirs and irrigation schemes in the Upper East Region of Ghana were investigated in this study. Water availability contrasted significantly between the two systems, the "Tanga" system having a higher amount of available water than did the "Weega" system. The concept of Relative Water Supply was used to confirm this disparity; Tanga had a Relative Water Supply of 5.7, compared to a value of 2.4 for Weega. It was also concluded that dissimilar water availability resulted in the evolution of very different irrigation methods and water management structures. Where there was more water available (Tanga), management could afford to be relaxed and the irrigation inefficient. Where there was less water available (Weega), management was well structured and irrigation efficient.

When analyzed at a high market price for crops grown, the Tanga system was half as profitable, in terms of total water used, but twice as profitable, in terms of returns to land, compared to the Weega system. Note that farmers in the Tanga system use more inputs. The difference in the profitability of water was attributed to the differing irrigation methods and management structures, and water availability.

During the course of 2007, PN46 developed a series of research tools, now in great demand by local partners in Ghana and Burkina Faso for use in capacity-building. These tools aim to answer the following kinds of questions: Where does the water flow? Where is the best place for a dam for water storage? How much water is available? How should stored water be used? What are the environmental consequences of small reservoirs? BFPs address similar questions but at the larger whole-basin scale.

Effective policies and institutional arrangements

"*Water productivity is constrained by lack of effective policies and institutional arrangements (good governance, legal framework and organizational structures) that create an environment that facilitates the behavioral changes towards sustainable water resources management and agricultural production. Effective institutional arrangements are urgently needed to minimize conflicts, improve water access for the poor, and enhance investments in water development and management and the adoption of integrated water resource management principles.*" (CPWF MTP 2006-08)

Often there are opportunities to increase basin level water productivity through policy and institutional innovations that encourage good governance, and foster sustainable water resource management and agricultural production. Effective institutional arrangements are needed to manage conflicts, improve water access for the poor, and enhance water-related investments – and to do so in ways compatible with the principles of integrated water resource management. Theme 5 conducts complementary research on conflict management, while Theme 2 also works in the area of encouraging access to water for the poor. Theme 4 makes sure that questions of basin-level water productivity are not forgotten in the process.

INSTITUTIONAL INTERVENTIONS AND THE DEVELOPMENT AND EFFECTIVE USE OF RESERVOIRS

The issue of basin-level water productivity and how it can be affected by ensembles of small reservoirs was introduced above. Water productivity of reservoirs is influenced by the range of uses to which they are put, and the positive and negative consequences of these uses. As a rule, small reservoirs are treated as common property. Their planning, development and management should be guided by institutions that facilitate the attainment of societal objectives, e.g., reduced mismatch between water demand and supply, equitable distribution of benefits and sharing of the water resource, and productive use of stored water. The fact that many small reservoirs are functioning sub-optimally and/or are falling into disrepair suggests problems of institutional failure.

Project PN46 reports that the main drivers for creating new and more responsive water management institutions in the Volta and Limpopo basins has been the poor performance of former institutions. Some countries in these basins have undertaken major policy reforms. Supranational agencies (Volta Basin Authority and Limpopo River Basin Commission) have been created to address transboundary water issues. In Ghana, the Water Resources Commission (WRC) oversees allocation of all water resources in the country and is creating sub-basin organizations to oversee water allocation and development. A White Volta sub-basin board has been set up to determine how district authorities, water users, and civil society can collaborate to manage water.

Many important water management institutions, however, are informal. The management of small dams is influenced by traditional leadership structures, which in turn may receive technical and financial assistance from various organizations. Small dam management often involves communities, NGOs and government.

While small reservoirs have a tremendous potential for mitigating the effects of drought, some reservoirs have failed because of lack of maintenance. A study of two reservoirs in the Upper East of Ghana, Tanga and Tonde, shows significant differences in the way rural communities manage their reservoirs. Tonde reservoir use seems more productive and sustainable compared to Tanga, even though the two communities enjoy similar geographical, climatological and formal institutional settings.

This prompted researchers to seek for reasons why reservoirs, which have a central function in supporting livelihoods, often fall into disrepair, even though knowledge and resources to maintain these systems are available. They posed the following research question: ‘How can social capital theory explain the differences in the management and usage of small reservoirs in the rural farming communities of the Tanga and Tonde systems?’ The study concluded that the farming community in the Tonde reservoir had a “more” social capital compared with Tanga and that this greater magnitude of social capital was manifested in at least three dimensions: (a) trust (b) networks and social cohesion and (c) inclusion. These differences, which are rooted in the history of the respective communities, played an important role in the management and use of reservoirs.

Tanga reservoir had experienced several incidences of water use conflict, compounded by lack of trust, central coordination and communication. The study concluded that dam site selection should not only be based on technical reasons, but on social factors as well, and that inadequate social capital can under some circumstances be enough of a reason to abandon or postpone reservoir construction. The study recommended that land ownership issues should be addressed before constructing reservoirs and that existing, strong cohesive, ethnic and gender (female) homogenous groups be actively involved in reservoir management.

COLLECTIVE ACTION AND WATER GOVERNANCE

One way to improve water productivity at the basin level might be through the voluntary reallocation of water resources from low- to high-productivity uses. 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 ecosystem services. At the whole-basin level, of course, there are likely to be an enormous number of stakeholders, each with their own interests. Understanding possible trade-offs and fostering a fully inclusive stakeholder dialogue is necessarily complex and difficult.

Project PN40 ("*Integrating Knowledge from Computational Modeling with Multi-Stakeholder Governance: Towards More Secure Livelihoods through Improved Tools for Integrated River Basin Management*") working in the Andean and Volta basins aims to strengthen multi-stakeholder governance structures in project sites in Ghana and 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. As described in the 2005 CPWF synthesis report,

"Initial project activities feature an analysis [and mapping] of the existing multi-stakeholder governance structures . . . 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."

The Chile case study focuses on market-oriented policy instruments associated with trade in water user rights, and the development of small-scale and large-scale irrigation infrastructure. Several critical issues have been identified. These include variation in individual incentives to participate in collective action; transaction costs associated with collective action; the effect of changes in institutional rules on individual incentive structures; and links among different stakeholders, e.g., between water users associations and irrigation system officials, between current rights holders and those who will gain from changes in water rights, and between stakeholders representing different interests, such as irrigators, hydropower and recreation.
Collective action problems in water trade were identified as (a) supply guarantees, (b) enforcement of water rights and (c) adequate and credible information. Collective action problems associated with small scale irrigation infrastructure development include (a) purchase and installation of water distribution monitoring equipment (b) overnight water storage facilities and (c) canal operation and maintenance. The study noted that monitoring flows provides information on actual quantities of water used by each member and that such information provides a pure public good even in the absence of water trading. One major concern is that of free-riders. Collective action problems associated with large-scale infrastructure affect a much larger group of users and can have substantial positive and negative externalities. Reconciling competing water interests and managing externalities requires institutional structures within which negotiations and bargaining can take place.

The Ghana case study focuses on major constraints/problems/conflicts associated with water governance. Issues vary by community and include declining water availability, deteriorating water quality, deficient infrastructure, inequitable allocation, and inadequate enforcement of the rules and regulations. The study also presents the negative social, economic and environmental impacts and the coping strategies of different communities.

GROUNDWATER GOVERNANCE

Groundwater problems emerge slowly and incrementally as a result of the cumulative effects of abstractions, contamination and changes in groundwater recharge. Timescales for remediation are also long, and impacts noticed today will persist for some time, even after the reversal of the original stresses. Problems related to groundwater include:

- Continuously dropping groundwater tables
- Increased costs of groundwater pumping
- Inequitable access (when access to water depends on affordability of pumping)
- Drying out of groundwater-dependent water bodies and ecosystems
- Increased problems with salinity or salt-water intrusion into groundwater
- Groundwater contamination

When groundwater is treated as a common property and is readily available over large areas it becomes vulnerable to over-exploitation. This occurs when large numbers of users individually choose to tap it for their own purposes. Groundwater science can help assess the status of the resource, understand aquifer vulnerability, and anticipate surface water – groundwater interactions. Wise management of groundwater requires that decision-makers understand the effect of policies on water use; the limitations of regulatory provisions in groundwater conservation; the role of different stakeholders in decision making; and the need for integrated approaches that balance productivity, equity and environmental goals.

Unfortunately, there is often a disconnect between groundwater technical specialists and decision makers charged with its sustainable use and management. There is a strong need to close the gap in perceptions and understanding between these two groups.
Within Theme 4, work on this issue is done by Project PN42 ("*Groundwater Governance in Asia: Capacity Building through Action Research in Indo-Gangetic (IGB) and Yellow River (YRB) Basins*"). PN42 builds on a substantial body of past work on groundwater and its management in East and South Asia and uses it in a research-based capacity-building program to strengthen groundwater governance. The project aims to develop teams of well-rounded, inter-disciplinary, problem-solving groundwater researchers and managers.

The project works with functionaries from government, civil society, media and academia in an inter-disciplinary inter-regional program of training and applied policy research. Training is organized around five modules:

- Resource characterization - hydraulics, hydrology, hydrogeology, soil physics, water lifting, irrigation systems, databases and GIS, etc.

- Agricultural water use –ecological principles, crop and livestock production, soil and water conservation, soil-water-plant relationships, irrigation practices, etc.

- Social science – economics, social processes, institutions, stratification and change, sociology, political systems, economics and human nature

- Governance and policies – the energy x irrigation nexus, property rights, institutions for water allocation, negotiating water rights, conflict management

The training of the first 40 practitioners took place in November 2006 in India. Each participant identified a research topic relevant to a groundwater management challenge in his or her own country. Activities included literature reviews, sensitization trips to different countries, development of a knowledge base, pilot studies, and synthesis research. Formal training was followed by an intensive program of pre-designed action research supervised by renowned professional. Of particular interest were the sensitization trips, in which participants have learned to understand groundwater issues, existing approaches to dealing with them, and further options for action.

EXAMPLES OF NEW INSIGHTS

Studies have generated new insights on a wide variety of topics. In northern China, results show that groundwater problems and their agricultural consequences are heterogeneous across space and change rapidly over time. Even well-targeted policies have been difficult to implement: despite the many formal laws and regulations now in existence, the government has had little success in controlling the extraction of groundwater or protecting its quality. In contrast, farmers have been responsive to increasing shortages. Individual farmers have taken control of most well and pump assets, developed groundwater markets, changed cropping patterns and adopted water savings technologies. While market forces and economic incentives can change use, public initiatives for agricultural groundwater regulation to balance short term economic efficiency with long resource sustainability are still needed.

Another study in India illustrates the extent to which policies can be "out of sync" with groundwater realities. In a state with 500-1000 mm rainfall, deep confined alluvial aquifers and rapid depletion of groundwater, state government policies suitable for the initial stages of groundwater development (free or highly subsidized electricity, rapid rural electrification, inexpensive credit for new well construction) remain in effect. In another state with 1400-2600 mm rainfall, unconfined aquifers and underexploited groundwater resources, policies that discourage groundwater development (expensive electricity, restrictions on new electricity connections, strict groundwater regulation) continue to prevail. The study makes the point that policies in India affecting groundwater often have little to do with scarcity, depletion and quality of groundwater and more to do with agrarian politics. The result is a situation in which groundwater use is strictly controlled where such control is *not* needed, and is not controlled where such control *is* needed.
Some generic lessons learned include the following:

- Groundwater problems vary spatially and temporally.

- Well-targeted technical and institutional intervention packages are needed to address them

- Even well targeted policies are difficult to implement because of the large number of groundwater users and the unpredictable outcomes of policy implementation

- Under predictable market conditions, farmers generally adapt to changes in groundwater tables, pumping costs and water pollution by changing cropping systems and adopting water saving technologies

- Groundwater use declines as groundwater depth and pumping costs increase

- Groundwater scarcity and related high water costs differentially affect the poor

Decision support tools and information

"*Basin level decision support tools and information are needed to generate the credible knowledge base needed to address contentious issues such as: (a) transboundary water allocation; (b) application of the "user-pays" and "polluter-pays" principles of integrated water resources management; (c) facilitating integration of different sources and uses of water and management organizations and levels; (d) enhancing participation of the poor and marginalized by packaging information on the issues that affect them in ways that they can understand and relate to; (e) facilitating wide-spread adoption of appropriate technologies and management strategies; and (f) for analyzing trade-offs between food and environmental security, equity versus economic efficiency, and allocating resources among competing users and users*." (CPWF MTP 2006-08)

Decision support and information systems (DSS) cut across all other Theme 4 objectives. They are fundamental to Theme 4 efforts to better understand the consequences for basin-level water productivity of activities described above, e.g.,

- Scaling out different kinds of new farm-level technologies featuring crops, livestock and/or the use of wastewater

- Investing in ensembles of small reservoirs in dry environments

- Implementing institutional and policy innovations to improved water resource governance, especially that touching on groundwater

In addition, DSS are central to other aspects of water management, e.g., the management of large dams. Issues here include operation decision-making, benefits sharing and environmental flows.

DAM DSS AND ENVIRONMENTAL FLOWS

Typically, decisions on releasing reservoir water are based on economic and safety considerations, with relatively little consideration of environmental consequences.

Natural water systems can tolerate a range of flow conditions. Their resilience allows them to recover from some degree of human use and abuse. However, there is a level of flow modification beyond which the river losses its ability to recover, and begins to lose its capacity to produce ecosystem services. Understanding what these limits are and implications for decisions on reservoir releases calls for the development of a DSS for managing environmental flows from reservoirs.

There has been some work done in the past on environmental flows. It has had limited application, however, because it has usually not been integrated into decision support systems used by decision-makers to absorb, process and use information. This is particularly true for the semi-structured or unstructured decision context in which environmental flow issues are often addressed. Under this context, it is important to make sure that decision makers understand the importance of the decisions they are taking, have access to understandable data and operate within a decision framework that makes explicit both the implications of different decisions and the trade-offs involved.

Theme 4 work on DSS for large dams is carried out through Project PN36 ("*Improved Planning of Large Dam Operation: Using Decision Support Systems to Optimize Livelihood Benefits, Safeguard Health and Protect the Environment*"), operating in the Nile basin.

Lessons learned by this project include the following:

- When faced with the challenge posed by water scarcity, environmental requirements are usually the first to be sacrificed

- A suitable legal framework is a necessary but not sufficient condition to ensure proper design and implementation of environmental flow targets

- Where dams are operated to meet the environmental flow requirements, a perception often persists that the dam created hardship for downstream people

- Good science is needed to estimate the patterns of flow that could be expected to achieve targets for river health conditions, and allow the calculation of losses to downstream communities to determine appropriate compensation

- Data continues to be a major constraint to generating information needed to manage environmental flows

- There is a general perception that incorporating environmental flow considerations can make investments in dams unprofitable

- Different people often attach different importance to different issues. As a consequence, negotiations on environmental flows can be difficult and contentious

DAM DSS AND BENEFIT SHARING

DSS is important when designing and implementing mechanisms for sharing benefits from large dams and other water resource development projects with project-affected communities. The rationale for do so includes the following:

- Dams generally generate significant rent that can be shared with communities

- There are ethical reasons for sharing benefits with project-affected population.

- Dam projects can be conceived as part of a strategy to foster regional and local development and to re-establish those displaced.

PN36 conducted a review of benefit sharing mechanisms used in 11 dam projects. The feasibility of a mechanism depends on having a suitable DSS. Mechanisms have included:

- Redistribution of part of the dams revenue to local or regional authorities in the form of royalties tied to power generation or water charges

- Establishment of development funds financed from hydropower sales

- Part or full ownership of the project by project-affected population (equity sharing)

- Levying revenue generating property taxes by local authorities

- Granting preferential electricity rates and fees for other water related services to local companies and project-affected population

The opportunities and problems associated with investment in ensembles of small reservoirs in dry environments were discussed above. It should be clear that DSS is essential in order to seize the opportunities and address the problems. Tools have been developed by PN46 to estimate the spatial coverage and capacity of reservoirs. Work continues in order on such topics as measuring evaporative losses, assessing health aspects, evaluating impacts on water quality, etc. The following approach to assessing reservoir spatial distribution gives a sense of approaches being used:

". . . the technique for automatic delineation of small reservoirs . . . utilizes Synthetic Aperture Radar images, high resolution images taken at radar frequencies from space. A statistical active contour model, developed for segmenting synthetic aperture radar (SAR) images into regions of homogeneous speckle statistics, is used for delineation of water reservoirs. The water boundaries are detected based on a technique that measures both the local tone and texture along the contour. To improve the accuracy, the density slicing and physical constraints such as position of dam wall, maximum area of reservoir are specified. The main drawback with the SAR images is the noise present in the SAR imagery." (Gichuki 2006)

Reflections and observations

Within the CPWF, Theme 4 scientists play a dual role. They conduct their own field- and catchment-level research on livestock water productivity, wastewater use, ensembles of small reservoirs, and large dam management. At the same time, they seek to add value to the work of other themes by identifying scaling out opportunities for new crop technologies, helping evaluate the downstream and cross-scale impacts of technical and institutional innovations, and helping develop decision-support systems based on the quantification and modeling of biophysical and socioeconomic processes.

Downstream consequences of farm-level interventions and cross-theme integration. It was noted earlier that Theme 1 projects typically take little account of downstream and cross-scale consequences of field-level interventions aimed at increasing crop water productivity. Theme 2 does conduct some research on catchment hydrology and how it is affected by land use. However, it is only in Theme 4 where a whole-basin perspective really begins to take hold. It might be advisable if Theme 4 research to evaluate the downstream/ cross-scale consequences of innovations were more systematically integrated into the work of other themes, and coordinated with the work of BFPs.

Enabling change and scaling out. Theme 4 deals with several topics not touched on by other themes, e.g., livestock water productivity and wastewater use in urban and peri-urban agriculture. As results in study areas begin to accumulate, questions begin to emerge about innovation systems, social processes for scaling out, and spatial targeting – in essence, the same questions being faced by other themes engaged in developing technical and institutional innovations.

Basin Focal Projects. Theme 4 and the Basin Focal Projects are natural allies. Both claim to be active in using quantitative datasets and models to examine at the basin-level the likely impacts of different kinds of interventions on water allocation, water and land productivity, and poverty and livelihoods. How might they combine forces to perform this role more systematically over larger areas?

Theme 5 – The global and national food and water system

> 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 [ecosystem] services derived from water resources . . .
>
> [Finally] the world is undergoing significant global warming and, with it, perturbations in regional and global water cycles. These shifts may undermine the capacity of agro-ecosystems to meet food needs and could trigger severe water shortages . . . 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.
>
> *CPWF synthesis report 2005*

Goal and research areas

CPWF Theme 5 is concerned with international, national and regional policies and institutions that directly or indirectly influence water and food – and how these policies and institutions can be shaped so that the poor benefit from, rather than being harmed by, the powerful and ubiquitous processes of global change. Research under Theme 5 covers two kinds of policies and the links between them: policies specific to the water sector, such as water institutions, economic incentives, and investment strategies; and policies that lie outside the water sector but indirectly affect water availability and quality, such as those on trade, climate, and macroeconomic issues. Taken together, Theme 5 projects and activities share the common goal of ". . . [supporting] policymaking both within and outside the water sector 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." (CPWF MTP 2006-2008).

Theme 5 participants seek to reach this goal by engaging in four distinct research areas:

- The role of globalization, trade, macroeconomic, and sectoral policies in achieving water and food security
- Incentives, investment and financing of agricultural water development and water supply
- Transboundary water policy and institutions
- Adapting to changes in the global water cycle

These four research areas are of immense interest to the global community. Theme 5 makes a distinct and unique contribution to the global debate on these issues by highlighting interactions among water, food, hunger, poverty, access, governance and technology. Moreover, Theme 5 helps provide the "big picture" context within which other CPWF activities can be interpreted and understood.

Globalization, trade, macroeconomic, and sectoral policies

"Globalization refers to the increased mobility of goods, services, capital, labor, information and technology throughout the world. A major engine of this trend is 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, make the poor more vulnerable and, in countries where agriculture is subsidized, reduce production and income. Moreover, trade and macroeconomic policies can have profound effects on the allocation and use of water and other natural resources such as land and forests. A better understanding of the impact of global and national policies on water resources and food systems is therefore essential to mitigate the adjustment process and avoid long-term harm." (MTP 2006-8).

In principle, this research area can cover an enormous range of issues, among them: ensuring rights to water for the poor under global change; harnessing globalization for improved water use efficiency; enhancing environmental policy, water quality and water-related ecosystems; assessing the role of virtual water for water and food security; and examining the role of economic incentives for improved livelihoods of the poor under increased trade and liberalization. In practice, only a few of these have been addressed.

MULTIPLE-STAKEHOLDER PLATFORMS, GOVERNANCE, AND POLICY FORMULATION

A key question for globalization focuses on water and its management as a means of helping achieve equitable development in the midst of global change and transformation: "How can the participation, rights and access to water of the poor, women, and socially excluded groups be established and safeguarded in the processes of global and national demographic, economic and political change that are shaping the developing regions?"

Important answers to this question are being developed by Project PN50 ("*Multi-scale Mekong Water Governance: Inter-disciplinary Research to Enhance Participatory Water Governance from Local Watershed to Regional Scales*"), which operates in the Mekong as well as smaller, neighboring river basins in Thailand. PN50 focuses on multi-stakeholder governance in the Mekong basin and ". . . aims at developing workable effective adaptive institutional arrangements for communities, stakeholder groups, and societies to cope with and adapt to the complex and dynamic changes in the Mekong River basin and other basins in the region."

The principle vehicle of PN50 is called "The Mekong Program on Water, Environment and Resilience (M-POWER)" which seeks to, " . . . democratize water governance and support sustainable livelihoods in the Mekong Region through action research . . . [where] water governance involves negotiating decisions about how water resources are used . . . .[and] democratization encompasses public participation and deliberation, separation of powers, trust in public institutions, social justice, protection of rights, representation, decentralization, and accountability."

M-POWER, among other things, engages in comparative studies of action research projects, drawing lessons through critical appraisal and sharing of experiences. Comparative studies are being conducted with regard to fisheries (for food security); flood management (to reduce the risk of disaster); irrigation (managing water supply and demand); hydropower (meeting energy needs fairly and sustainably); upper watersheds (securing resilience in livelihoods), and waterworks (providing water for households and industry). Synthesis research that cuts across these comparative studies aims to draw attention to critical principles and practices essential to the democratization of water governance: social justice, dialogue, appropriate policies, and knowledge sharing.

For each of these, a multi-organization research team organizes events for interaction and debate. Workshops have been held on cooperation in management of upland watershed development; flood risks; institutional dimensions of global environmental change; and informed and fair water and trade futures. Some highlights are listed below:

The research group focusing on floods observed that flood-related disaster management has normally been understood by governments in the Mekong region as a technical problem – but that it requires attention to institutional and political issues as well.

The research group on hydropower felt compelled to go beyond considerations of water and hydropower to scrutinize more carefully the whole system of energy planning and provision. While it is true that energy is needed for development, findings show that (large-scale) hydropower is not always the optimal strategy to meet these needs.

The research group focusing on upper watersheds worked on achieving a better understanding of the characteristics and similarities across northern Lao PDR, Yunnan province of China, northern Vietnam and northern Thailand. Striking parallels were found regarding land-use systems, property rights, and livelihood needs. There are also many shared equity and welfare concerns, given that many people in these landscapes are from ethnic minority cultures that historically have been left out of key decision-making processes that affect their lives.

One major event co-organized by M-POWER (with the World Conservation Union, the Thailand Environment Institute, and IWMI) was the Mekong Region Waters Dialogue (6-7 July 2006, Vientiane). This dialogue brought together the Mekong River Commission (MRC); key government officials from Mekong basin countries; local and external university students and staff; international and local NGOs; major development assistance agencies (Asian Development Bank, AusAID, the World Bank,); and private companies working in water infrastructure development (Italian-Thai Company).

The Mekong Region Waters Dialogue was an example of a "multi-stakeholder platform". Participants gave a very realistic assessment of what can be expected from such an event:

"Multi-stakeholder processes do not necessarily solve problems, but they do help disputing parties to understand at least partly other stakeholders' views and interests. Those involved have stressed repeatedly the crucial importance of the process itself as a communication and visioning process [sic]. People may not necessarily come to the table to learn or to bargain, but they find it very valuable to hear about what is going on. However, providing only political space to different stakeholders is usually not enough. Training, empowerment and working towards quick wins are necessary to keep people motivated. "Third parties" such as local and external knowledge brokers can play an important role in this effort . . . Multi-stakeholder platforms do not cut out politics; they are an integral part of it!" [1]

The CPWF and Theme 5, through Project PN50, played an important role in fostering this dialogue. Dialogue conveners are following up agreements made in Vientiane and are providing periodic updates and reports to participants and stakeholders. As a result of the Mekong Region Waters Dialogue, there has been greater recognition by Mekong country states and multilaterals that they must improve their level of engagement with other sectors in Mekong societies. Some immediate outcomes include:

- The Ministry of Foreign Affairs (Denmark) and the IUCN have recommended to the Mekong River Commission (MRC) that a multi-stakeholder consultation be held for inception report of the MRC's Basin Development Program.

- The World Bank has included a new component into the next phase of the GEF- funded Water Utilization Program of the MRC, "Component 4: Multi-Stakeholder Water Governance: Sharing Different Visions, Building Partnerships, Knowledge Brokering."

- The MWRAS (Mekong Water Resources Assistance Strategy) process, a collaborative product of the World Bank and ADB, was publicly evaluated and formally critiqued in follow-up correspondence from the Dialogue conveners. MWRAS has now been put to rest, and a reframed Mekong-IWRM is being developed in which the process and content are taking on board many Dialogue recommendations.

- Thailand's Energy Minister, who attended the Dialogue, has invited a sub-group to join smaller meetings to focus on Thailand-Myanmar energy projects that may re-think a policy shift in the proposed construction of dams in the Salween River.

A further challenge is to bring this experience to bear in other river basins, to examine how multiple-stakeholder platforms can be used more widely, and to apply the lessons learned in PN50 to inform future CPWF research investments and approaches.

During 2007, PN50 team members more thoroughly documented and published their various analyses in the form of books, journal articles and other publications. In this form they are considered to be available for use by policymakers in the region.

Further insights on multi-stakeholder platforms and their role in ensuring rights for the poor under global change processes were provided by a Theme 5 synthesis product, titled "Water Rights Reform: Lessons for Institutional Design" (Bruns et al. eds. 2005) Based on case studies in six continents and drawing on additional practical experience and research in multiple countries and regions, the book editors find that the following steps can be important for enhanced water rights and access by the poor:

Redesigning governance—forming more inclusive forums to negotiate agreements and rules—including multi-stakeholder platforms. Redesigning basin water governance often requires a "constitutional" level process of collective action to include new stakeholders and a

1 IUCN, TEI, IWMI, and M-POWER, 2007. Exploring Water Futures Together: Mekong Region Waters Dialogue. Vientiane, July, 2006.

wider scope for water management, (both geographically and across sectors), restructuring who will be involved and how decisions will be made. In such a process, stakeholder participation may be an essential means to incorporate different views and interests. Integrating environmental considerations, or for that matter, agricultural and irrigation concerns, into water allocation illustrates some of the constitutional level complications of including different stakeholders and issues.

Resolving tenure—establishing rules and other institutional arrangements to clarify rights and provide recourse for settling disputes. Resolving water tenure requires determining the scope of rights to access, withdraw, manage, exclude, and transfer. Resolving tenure focuses on distributional issues of who gets what, security of access to resources, with major implications for social equity. At the operational level, rules are then put into practice: recognizing rights, allocating water, and dealing with disputes. One subset of rules may well concern transfers (point 3) in which case reallocation could become primarily an operational level process of transactions among users, or between users and those agencies mediating voluntary or involuntary transfers. Administrative agencies usually play a major role in formulating rules, formally recognizing tenure rights, and resolving conflicts. Resolving tenure usually relies on delegating duties to agencies to formulate more detailed regulations and put them into operation, so the problems of aligning agents' incentives and monitoring their behavior are crucial. There are also technical complications in revising rules to include additional resource attributes and management objectives, such as environmental concerns with water quality and low flows, and in putting such rules into operation.

Regulating transfers—implementing routine mechanisms for temporary and permanent transfers, including relevant safeguards. Transfers can only occur where rights holders can make credible commitments, based on rights that can be defended against infringement, and enforceable agreements for temporary or permanent transfers between users. Similarly, compensation for involuntary reallocation depends upon the state's commitment to respect existing rights. Transfers can contribute to economic gains from greater efficiency, so that the productivity of water increases in value, while safeguards may help mitigate adverse impacts on equity and the environment. Market exchange relationships become more prominent with transfers, as voluntary trading forms prices, or in negotiating possible compensation for losing access to water (involuntary water reallocation).

While these overall messages are important, no country starts with a blank slate when undertaking water rights reform. Participants at the African Water Laws Workshop (2005), which was held together with PN47 ("*Transboundary Water Governance for Agricultural and Economic Growth and Improved Livelihoods in the Limpopo and Volta Basins: Towards African Indigenous Models of Governance*") called for research and capacity building to record and understand community-based water arrangements and the interface with other legal frameworks, including the gender dynamics of how water is used for multiple purposes. This "baseline" is critical for identifying the range of stakeholders and assessing how different types of reforms are likely to affect each group, with particular emphasis on poor and marginalized groups.

REVISITING THE NOTION OF "GLOBAL WATER POLICIES" AND IMPLICATIONS FOR THE CPWF

Theme 5 research in the area of "globalization and water" has not been restricted to its participation in Project PN50. During 2005, the Theme 5 team held a workshop in Costa Rica focusing on "Globalization and Trade: Implications for Water and Food Security". This workshop (described in more detail in the 2005 CPWF synthesis document) aimed to identify avenues for policy reform, research gaps and opportunities for collaboration among disciplines.

In 2006, Theme 5 partners and participants organized a session on "Global Water Policies" at the International Forum on Water and Food (Vientiane, November 2006). The focus of this session was to more accurately (and more broadly) define the notion of "global water policy" and the implications of this broader definition for the CPWF research agenda. Session participants identified five categories of global water policies:

- **Strictly global water policies,** e.g., the Convention on the Law of the Non-navigational Uses of International Watercourses

- **Global policies that include water**, e.g., GATS [General Agreement on Trade and Services] policies on opening up water services to competition from other member countries, or water-related trade sanctions and restrictions

- **Non-water global policies that impact water**, e.g., the Codex Alimentarius on food safety, or energy policies dealing with bio-fuels

- **Water non-global policies with global, regional and basin-scale impacts,** e.g., policies regarding water and sewage treatment plants, hydropower development, water pricing and cost recovery, irrigation management, etc.

● **Non-water non-global policies with global, regional and basin-scale impacts,** [sic] e.g., policies affecting agricultural input use, or the development of new crop varieties.

The bottom line is that both water and non-water policies are important for water and food outcomes at a larger scale. To date the CPWF has invested relatively few resources in examining links among global water and non-water policies and water and food outcomes. According to session participants, priorities include research on climate change, uncertainty and risk; research on policy processes, including frameworks for human rights, conflict resolution, water sharing, and determinants for their adoption; and research on bio-fuels, trade impacts, and disasters.[2]

Whether the above represent priorities for research by the CPWF itself, or by other concerned stakeholders, remains to be determined.

Incentives, investment and financing of agricultural water development

"In much of the world, low water prices and high subsidies for capital investment and water infrastructure maintenance are counterproductive. They threaten effective and equitable water allocation and siphon off financial resources needed for further development of agricultural and urban water supplies. What makes the problem particularly serious is that future water development will require huge investments. New sources of water, for example, are increasingly difficult and expensive to exploit. At the same time, construction of traditional dams and reservoirs involves enormous environmental and social costs, especially the dislocation and resettlement of people. Wise planning of new water projects demands more accurate estimates of the costs and benefits of alternative investments in supply and demand management strategies, by country and region . . . research will develop methods and tools to help policymakers to identify viable financing and incentive schemes and allocate resources more effectively." (CPWF MTP 2006-08)

When water is scarce, it can make sense to develop new sources of water. 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 large-scale investment in water supply, including large dams.[3] Of the various approved first-call competitive grant projects, only one is directly focused on this research area. This is project PN48 ("*Strategic Analysis of India's National River-Linking Project (NRLP)*") focusing on all of India, including the Indus and Ganges basins. The project seeks to conduct a strategic analysis of India's National River Linking Project, arguably one of the largest proposed water development projects in the history of humanity – and one of the most controversial.

The National River Linking Project (NRLP) is designed to ease water shortages in western and southern India while mitigating the impacts of recurrent floods in the eastern parts of the Ganges basin. At first glance, the logic is simple: western and southern India is dry and drought-prone; it needs more water. Eastern India is wet and flood-prone; it has too much water. Why not convey surplus water in the east to deficit areas in the west?

Many have argued that additional water resources are needed for western and southern India. Rural populations are growing, food demand increasing, cities expanding, and urban and industrial water requirements rising – even while water is becoming increasingly scarce. Others have argued that rural population will soon plateau and begin to fall, that food security can be achieved through more efficient use of rainfall, that demand management can take care of urban and industrial needs, and that alternative approaches to poverty reduction are more cost-effective. Proponents describe the immense benefits to the nation; critics point out the financial, environmental and social costs. The financial costs alone are said to be on the order of $100-200 billion.

Arguments in favor or against the NRLP often go to extremes, perhaps because the dialogue lacks a sound informational base. Project PN48 is designed to promote a balanced, analytical, national discourse on NRLP proposals. During its Phase I, PN48 published several working papers and reports on such diverse topics as: the future of irrigation; agriculture and the WTO; environmental flow requirements of rivers; demographic projections; the future of food grain production; urban population growth; water productivity and water savings; consumption patterns and changes in the structure of food demand; groundwater management; labor migration; and water harvesting and rainwater management. The range of topics studied is indeed impressive.

The project was planned in terms of three phases: (1) research on drivers of water supply and demand, projected to 2025/2050; (2) research on the adequacy and

2 Session 18 Summary Report, Global Water Policies, International Forum on Water and Food, drafted by Claudia Ringer.
3 Other research areas under Theme 5 include 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, research versus extension, etc.] and between agriculture and complementary service sectors [education, health, rural roads, etc.].

cost-effectiveness of the NRLP in matching water supply and demand at the national level, and how the social benefits from any such investment can be maximized; (3) development of suggestions for a "Plan B" – what to do if the NRLP fails to take off. [4]

The project entered into Phase II in 2006, with the intention of looking at the picture as a whole, including transboundary issues and the roles of Nepal and Bangladesh in making such a project viable. Unfortunately, a lack of adequate information on the proposed river links and the flow data of Himalayan river basins became major constraints. The objective of the second phase was adjusted. Instead of a complete cost benefit analysis of the project as a whole, a two-track system was designed involving both national and detailed link case studies. These will provide a vast amount of information for the discourse in assessing the social cost and benefits of NRLP.

During 2007, most research activities were finished and began to be published. A proposal was submitted to Oxford University Press for the publishing of the synthesis of research results from the first phase. In addition, a national workshop on river interlinking was held in New Delhi in October. The workshop was well attended by policymakers (including the chairman of the national task force on interlinking of rivers, and members of the National Water Development Board – NWDB), NGOs, researchers and civil society. As a result of the workshop, PN48 researchers were requested present the findings in a separate meeting with the NWDB.

Project PN48 is in many ways unique in the CPWF portfolio. It is engaged in assessing what might be viewed as the quintessential water development project. There is great uncertainty regarding the benefits and costs of the NRLP, though both are undoubtedly enormous. PN48 will foster an improved understanding of the likely magnitude and social distribution of different categories of costs and benefits. By engaging in this project, Theme 5 strengthens the capacity of the CP and its partners and stakeholders to examine water development projects, and their utility in poverty reduction, at the national scale for one of only two countries whose water and food situation will directly impact all other countries as a result of increased integration of world economies as well as their sheer size and economic power.

4 The above paragraphs draw on two sources: the "PN48 First Annual Progress Report April 2005 to March 2006"; and an unpublished draft paper by Tushaar Shah, Upali Amrasinghe and Peter McCornick entitled "India's River Linking Project: The State of the Debate"

Transboundary water policy and institutions

"*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 main challenge is to build the institutional capacity and culture of cooperation needed to prevent economic, political or environmental crises before they happen. This research will investigate arrangements for sharing transboundary waters and processes for resolving or avoiding conflicts.*" (MTP 2006-08)

In principle, this research area can embrace the following issues: 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, and food security into transboundary river basin agreements. Theme 5 partners and participants framed the following key question: "To what degree do different methods for conflict resolution or negotiation provide access and protection to the poor, women or other disadvantaged groups?"

This question relates back to safeguarding water rights under global change as water rights are the foundation upon which negotiations and conflict resolution can take place. Theme 5's focus on negotiation across boundaries is reflected in Project PN47 ("*Transboundary Water Governance for Agricultural and Economic Growth and Improved Livelihoods in the Limpopo and Volta Basins: Towards African Indigenous Models of Governance*"), which reviews transboundary water management in sub-Saharan Africa, particularly the Limpopo and Volta basins. With over 60 international river basins in Africa and virtually every African country sharing at least one of them, this becomes a crucial issue. Implementation of basin-level integrated water resources management in Africa requires international cooperation among riparian countries.

Interventions that aim to shape transboundary water management in Africa must take account of the following factors: poverty in Africa is widespread; overcoming rural poverty often depends on reliable access to water; the interests of the poor are rarely considered during international negotiations on water rights; and indigenous arrangements in land and water management continue to be very important in Africa.

The approach taken by PN47 is to develop both "top-down" and "bottom-up" profiles of water governance issues in two case study basins, the Volta and the Limpopo. Local partners have formed a network to develop recommendations for incorporating indigenous principles into transboundary water management agreements and institutions. During 2005, PN47 researchers and partners developed the top-down basin profiles, and created and made public a database of African water laws (www.africanwaterlaws.com).

During 2006, the project made public the top-down hydro-political profiles for the Limpopo and Volta basins. These profiles present water management institutional histories from pre-colonial times through present day. They are structured such that issues and significant events involving the use and control of water in riparian countries are recognized and explored. The top-down assessment is being complemented by national level case studies based on data collected during a year-long field study of local level, indigenous water governance arrangements.

In general, it was found that under customary law, riparian (contiguous, neighboring) communities recognized the right of use by all. That is, a basic water use principle among riparian communities was that each user may use available water provided sufficient water is left for other users. "In essence, the water resource was viewed as community property and a free good. In practice the water resource was shared during periods of scarcity while other sources of water were explored such as digging shallow wells near river banks." Ownership of water resources was typically vested in traditional authorities who "acted as guardians and regulators of water and land resources for and on behalf of the gods and ancestors ensuring the protection and sustainable use of these resources".

During the colonial and later periods, these customary laws were in part over-ridden by a variety of statutes and regulatory agencies that changed and evolved over time. Some of these "commodified" what had been a basic right and/ or divorced water from land management. More recently, water governance has come to feature decentralization away from bureaucracies, greater participation of stakeholders in planning, an increase in decision making by water users, and attention to integrated water management principles.

Some findings from PN47 are unexpected and provocative. Three of these are:

- The very nature of indigenous water management practices and institutions is dynamic and flexible, with adaptive capacity to respond to even sudden changes in environmental, social or economic factors.

- Leaders establishing multiple-partner, multiple objective water management institutions should keep in mind a series of customary principles in use:

    - *Shared interest in protecting water resources for sustained use*
    - *Common vision and understanding of use rights and principles*
    - *Transparency in decision making and accumulation of benefits*
    - *Clear procedures for individual participation in institutional functions*
    - *Confidence that all will participate and all will follow the rules*
    - *Share common language(s) of understanding.*

- "Integrated water resource management" (IWRM) generally promotes hydrological units of analysis rather than those pertaining to national, political, cultural, or linguistic boundaries. This raises the question of how customary water arrangements and IWRM can complement each other. The multi-stakeholder platforms used by PN50 might be helpful.

Since the project has just been completed (December 2007), it is difficult to say exactly how the growing body of research based on the treaty collection will eventually affect policy. However, there is evidence that the results are moving down the project's desired impact pathways and are influencing thinking on transboundary water management in Africa. For example, the database and related documents have been cited in a growing body of African Ministers' Council on Water, United Nations and World Bank documents related to Africa and at least one African water affairs ministry. Beyond Africa, they have served as input to solutions to water sharing problems between Israel and Jordan and have been referenced by the Council on Foreign Relations and The Asia Society. The insights from the project based studies are also making their way into the academic literature and, despite recent completion, have already been cited in the refereed work of others, taking the original data and research to new levels.

Adapting to changes in the global water cycle

"Water is not only vital for direct human consumption; it also contributes to the quantity and quality of ecosystem services such as food production, filtering of environmental pollutants, and the maintenance of healthy natural habitats for fauna and flora. But the world now faces the likely prospect of significant climate change

and, with it, perturbations in global water cycles. These shifts may undermine the capacity of agroecosystems to meet food needs and could trigger severe water shortages especially for vulnerable populations. Higher temperatures and the associated changes in hydrological regimes may, for example, shorten growing seasons and increase the frequency of extreme and destructive weather events. They may also have indirect effects on social and economic systems. In the short term, human influences, such as altered land-use patterns, urbanization, elimination of wetlands, and high nutrient loads of water systems, may further undermine the global water cycle's capacity to support food production. Research is required to investigate international and national policies that can help the rural poor to adapt to climate variability and climate change." (CPWF MTP 2006-08)

This research area focuses on 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.

Theme 5 partners and participants have framed the following key questions: "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?"

Theme 5 addresses this supremely important issue through Project PN53 ("*Food and water security under global change: developing adaptive capacity with a focus on rural Africa*"), which concentrates on sub-Saharan Africa, particularly the countries of Ethiopia (Nile basin) and South Africa (Limpopo basin). This project aims to provide policymakers and stakeholders in Ethiopia and South Africa (particularly farmers and others who will feel the effects of global change) with tools to better understand, analyze, and form policy decisions leading to better adaptation. It is anticipated that the least affluent stakeholders will benefit most from the results and insights gained. Impacts on women, and poor farmers, and other groups who are often overlooked will be accounted for explicitly in the assessment of global change impacts and adaptation strategies.

The project uses the following approach:
Understanding the challenge: Appreciating the likely impacts of global change on rural Africa in general and on Ethiopia and South Africa, in particular; characterizing rural people's vulnerability and assessing their adaptive capacity

Finding solutions: Identifying a range of adaptation and mitigation strategies for rural Africa and specifically for Ethiopia and South Africa; analysis of alternative strategies using an integrated policy analysis tool

Building local scientific capacity: Enhancing national and international capacity for climate change and economic policy analysis through training of students

During 2005, progress was made in consulting with stakeholders; forging partnerships in Ethiopia and South Africa; developing and adapting suitable general equilibrium and other models (e.g., IMPACT); and collecting data. Progress continued in 2006 with the publishing of review papers on vulnerability and adaptation strategies in South Africa and Ethiopia; completion of household surveys in both countries; climate change downscaling activities; and further advances in model adaptation.

Early results from the household surveys conducted in the two countries indicate that most farmers in the Limpopo (South Africa – 90%) and the Nile (Ethiopia – 60%) claim to perceive long-term changes in precipitation (reduced) and temperature (increased). They report having developed several adaptive strategies. These include changes in crop variety, adjustments in crop selection, shifts in planting dates, investment in water harvesting practices, increased use of irrigation and – in some instances – abandonment of farming (sometimes accompanied by a shift to livestock grazing). A full 40% of farmers, however, indicated no change in farming practices. In Ethiopia this was attributed to lack of information about options, whereas in South Africa it was explained by lack of access to credit, markets, or water, or insecure or inadequate property rights. [5]

Theme 5 also actively engaged research and analysis with other global change research systems, including GWSP (Global Water Systems Project) – which led to the publication of a book (Crasswell et al 2007). Theme 5 also participated in the CGIAR Inter-Center Working Group on Climate Change and will remain engaged with a potential future climate change CP.

5 Information in this section was drawn from the First and Second Annual PN53 Project Reports, and from a Most Significant Change story entitled, "Importance of Complementary policies in Farm-Level Climate Change Adaptation Strategies" presented at the International Forum on Water and Food, Vientiane, November 2006.

Reflections and observations

In its breadth of scope and range of interests, Theme 5 is unique within the CPWF. It deals with high profile issues of immense interest to the global community: globalization and trade; investment and financing of water resource development and water supply; transboundary water policies and conflict management; and threats to water resources and livelihoods posed by climate change.

Theme 5 has a role in contributing to the global debate on these questions. It does this through knowledge generation and sharing, with an emphasis on international public goods. However, it also has a role within the CPWF. The overall efficiency and effectiveness of the Program in part depends on systematically integrating Theme 5 activities and endeavors with those of other themes.

The policy and institutional context analyzed by Theme 5 projects may in some instances pre-determine the extent to which farm-level technical or institutional innovations, topics of research by Themes 1-4, have a chance of becoming widely adopted. It might be useful to have a mechanism whereby such information is systematically shared and applied. Similarly, Theme 5 research may detect trends which call for new directions in research on crop water productivity or aquatic ecosystems. One obvious example is the work of Theme 5 on "changes in the global water cycle". Lessons learned should be of immense interest to Theme 1 researchers working on drought tolerance and drought-related risk management in rainfed ecosystems – and vice-versa.

Themes 1 – 4 all face common challenge of "scaling up and out". What is the social process whereby prototype technologies or successful case studies are transformed into something that affects huge human populations over large areas? This question applies to drought tolerant varieties and water harvesting technologies – but also to wastewater management practices, PES schemes, MUS systems, social learning processes to foster collective action, governance mechanisms for water allocation, and many more.

Theme 5 is not exempt. Similar challenges for scaling up and out exist for such institutional innovations as multi-stakeholder platforms – how to "bring this experience to bear in other river basins, to examine how multiple-stakeholder platforms can be used more widely, and to apply the lessons learned in PN50 to inform future CPWF research investments and approaches". Scaling up and out questions even apply to the application of principles of indigenous water rights to transboundary contexts.

Some of the research questions posed by Theme 5 are critically important – and at the same time breathtaking in their audacity.

One example is the following: "*How should investments be allocated to reduce poverty, directly for water development, or in water-related or water-supporting sectors, including agricultural research and other kinds of physical infrastructure and social investments such as education, health and nutrition?*" The question is a good one – to what extent are investments in water resource development more effective in reducing poverty than other kinds of public expenditure? While it may be relatively easy to conduct a few case studies on this question, how does one systematically come to closure on this question at a global level?

Theme 5 researchers might wish to reflect on their own relative advantage in a world populated with think tanks, international institutes, universities and other centers of expertise. Theme 5 can't do it all. Having said that, what is the peculiar, distinct role of Theme 5 in relation to collaborators and allies on the one hand, and companions within the CPWF on the other? There is no single answer – the task of Theme 5, like that of the CP itself, will continue to evolve and adapt.

Cross-Theme integration

Problems of poverty, food security and livelihoods are infinitely complex. So are the multifaceted ways in which they are interrelated with water scarcity and lack of access to or development of water. In any given river basin, these problems are likely to affect different groups of people in different ways. Adding on environmental and ecological considerations does not simplify matters. Nonetheless, the main threads are not impossible to disentangle.

People's well-being is in part influenced by access to water (and other resources) and the productivity with which these resources are used. In any particular location in a basin, water access and availability are influenced by how water is managed by upstream users, and by water-related policies and institutions (including investments in water resource development). Downstream users can provide incentives to upstream users to manage water more parsimoniously. Environmental flows and ecosystem services are "users" of water, just like crop production or urban consumption.

When water is scarce, increased productivity can help enhance food production while making more water available for downstream users. Water productivity – whether measured with respect to crops, livestock, fish, or ecosystem services – can be increased through innovative technologies and institutional arrangements, and policies that encourage such innovation. All of this unfolds in an evolving and dynamic global environment of policy, institutional (and climate) change that sets the limits to what is feasible and what is not.

Taken as a group, the five CPWF themes touch on all of these areas. Theme 1 works to increase crop water productivity, while Themes 3 and 4 work on fisheries and livestock water productivity, respectively. Themes 2 and 4 work on measuring – and even anticipating – how downstream water availability changes in response to adjustments in upstream water management. All themes keep track of policies and institutions, with Theme 2 specializing in catchment-level institutional innovations and Theme 5 keeping track of global policies that influence what everyone else is doing. Several themes are committed to understanding and improving governance – the process whereby decisions affecting water allocation and water management are made.

Themes must specialize. Everyone can't be always trying to do everything. Theme 2, for example, concentrates on understanding poverty and how it is affected by water-related issues and practices. This does not mean that Theme 1 or Theme 4 consider poverty to be irrelevant or uninteresting. Theme 1, in contrast, concentrates on boosting farm-level crop water productivity. Other themes do not find this meaningless – in fact, such increases can be critically important in reducing poverty (Theme 2), in making more water available for ecosystem services (Theme 3) or in increasing water availability for urban centers and thereby avoiding a need to invest in expensive water infrastructure (Theme 5). And because all themes are part of the CP, and the CP has an impact orientation, all themes are deeply interested in impact pathways and innovations systems.

People from different themes and projects within themes are willing to work together. Perhaps what is lacking is a way to systematize the process for doing so. This can be achieved – without major changes in theme composition or focus – by improved cross-theme integration (and improved integration with BFPs: discussed below). Here are a few suggestions:

INNOVATION SYSTEMS AND SCALING OUT

All themes working in a specific basin might wish to more closely integrate their efforts to foster and encourage innovation systems.

As noted above for Theme 1, "The challenge is to facilitate the creation of dynamic innovation systems for tailoring prototypes to local environmental and socio-economic circumstances. Innovation systems are an organic, dynamic, self-directed social process, a co-evolution of interventions and stakeholders. At its best, this process grows and gathers speed, with increasing involvement by more stakeholders – until, at some point (the 'tipping point'), a technology begins to be spontaneously and widely adopted, a suitable policy is shaped and implemented, or an institutional innovation takes hold."

Innovation can be facilitated and encouraged, and networks, properly managed, are the right tool for the job.

Note that the relevance of innovation systems and scaling out is not restricted to new technologies. "This question [of innovation systems and scaling out] applies to drought tolerant varieties and water harvesting technologies – but also to wastewater management practices, PES schemes, MUS systems, social learning processes to foster collective action, governance mechanisms for water allocation, and many more . . . Theme 5 is not exempt. Similar challenges for scaling up and out exist for such institutional innovations as multi-stakeholder platforms . . . Scaling up and out questions even apply to the application of principles of indigenous water rights to transboundary contexts."

UNDERSTANDING AND MANAGING DOWNSTREAM AND CROSS-SCALE CONSEQUENCES OF INNOVATION

All themes working in a specific basin might wish to more closely integrate their efforts to understand and manage the downstream and cross-scale consequences of innovation.

It would be highly desirable to develop systematic links between projects developing new farm-level technologies or catchment-level institutional innovations, and projects with the capacity to model the basin-level consequences of such technologies and innovations. Both kinds of projects are distributed across several themes.

As one example, a question might be raised in the context of Theme 1, " . . . if aerobic rice practices were to be adopted on 5m ha in China, what might be the effects on the quantity and quality of water for downstream users? If more water were to become available, how might this most effectively be used?"

Similar questions were raised for Theme 2, "One of Theme 2's three objectives is to achieve a better 'Understanding [of] biophysical and social processes in catchments', including 'Understanding catchment hydrology and the impacts of land use' . . . Improved cross-Theme integration could facilitate the use by all themes of the modeling tools being developed by Theme 2, thereby facilitating the consistent assessment of downstream consequences for a far larger set of land use options."

Theme 4 needs to be part of this. It was also pointed out that it is . . . "only in Theme 4 where a whole-basin perspective begins to take hold. It might be best if Theme 4 research to track and evaluate the downstream/ cross-scale consequences of innovations were not confined to a few model projects. This may be an area where a more systematic effort might pay off.

This would require some synchronization of effort among the five themes, and the Basin Focal Projects." An even better option might be to concentrate all whole-basin modeling, and evaluation of the downstream/ cross-scale consequences of innovations, in the BFPs.

WATER, TECHNICAL CHANGE AND POVERTY

All themes working in a specific basin might wish to more closely integrate their efforts to assess the relative capacity of water-related interventions to address questions of poverty and food security.

Theme 2 researchers recognized that, "Sometimes poverty can be reduced by improving access to water, or by improving the productivity with which water is used. Other times, however, the real opportunities to reduce poverty lie elsewhere. It is even possible to envision occasions in which effective poverty reduction strategies result in water degradation, with trade-offs between peoples' livelihoods and environmental conservation." Understanding the links between water and poverty is indeed central to CP program planning and priority setting.

This issue is relevant to all themes. In the above section on Theme 1, the following question was posed: "If your project is entirely successful in developing and fostering widespread adoption of new technologies, policies and institutions to improve crop water productivity, how far does this take you towards meeting developmental goals? . . . To what extent does complete success in improving crop water productivity help solve problems of poverty and food insecurity?"

It was Theme 5 that raised this question at the broadest possible level. They asked, "How should investments be allocated to reduce poverty, directly for water development, or in water-related or water-supporting sectors, including agricultural research and other kinds of physical infrastructure and social investments such as education, health and nutrition?" In other words, to what extent are investments in water resource development more effective in reducing poverty than other kinds of public expenditure? And, going beyond *ad hoc* case studies, how does one systematically come to closure on this question at a global level?

GLOBAL POLICY AND LOCAL INNOVATION

There is likely to be value in considering a more systematic integration of the work of Theme 5 with that of other themes.

Earlier in this report, the possibility was raised that "The policy and institutional context analyzed by Theme 5 projects may in some instances pre-determine the extent to which farm-level technical or institutional innovations, topics of research by Themes 1-4, will ever have a chance of becoming widely adopted. It might be useful to have a mechanism whereby such information is systematically shared."

THE SUSTAINABILITY OF INSTITUTIONAL INNOVATIONS

Several Theme 1 projects intend to foster the development of local institutions for seed multiplication and dissemination. In doing so, these projects might wish to examine the lessons learned by others who have taken this path. Institutional innovation in seed systems is notorious for problems with institutional sustainability.

Theme 2 has a particularly heavy emphasis on institutional innovations, e.g., PES and MUS. Several themes also work on fostering (institutional) mechanisms for improving water resource governance. Issues of institutional sustainability are just as relevant here.

THEMATIC RESEARCH AND BASIN FOCAL PROJECTS

Reasons for fostering closer integration of effort across themes are also valid for encouraging greater integration of effort between thematic research and that conducted by Basin Focal Projects. BFPs are designed to have the capacity for systematic and comprehensive analysis at the whole basin level of issues touching on water and livelihoods. In particular, Theme 4 and the Basin Focal Projects would seem to be natural allies. Both claim to be active in using quantitative datasets and models to examine at the basin-level the likely impacts of different kinds of interventions on water allocation, water and land productivity, and poverty and livelihoods. How might they combine forces to perform this role more systematically over larger areas?

Basin Focal Projects

"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." (2005 CPWF synthesis report)

BFP structure and function

Discussion in previous sections has focused largely on first round competitive projects, organized by Theme. Regardless of their individual qualities, however, and when taken as a group for a particular basin, these projects do not necessarily add up to a coherent and systematic approach to addressing problems of water and food. From its very earliest days, the CPWF has recognized this. One response has been investment in synthesis research, for example, the present report.

Another, more comprehensive response has been the establishment of Basin Focal Projects (BFPs). A first round of BFPs was implemented in the Karkheh, Mekong, São Francisco and Volta river basins. Commissioned in 2005, most of these will finish their work in 2008. A second round of BFPs to be launched in 2008 will cover the Andes, Indus-Ganges, Limpopo, Nile, and Yellow river basins.

BFPs are designed to perform two functions: (1) provide whole-basin assessments of water availability, poverty, food security, and water productivity, and (2) examine water-related institutional and technical interventions, to ascertain the extent to which they might contribute to poverty reduction, livelihoods resilience, and environmental conservation. In performing these functions, they take account of how upstream interventions may affect downstream water uses and users. To perform these functions, research in BFPs has been organized around six work packages.

WORK PACKAGE 1:
Water, poverty and food security. How are water, poverty, food security and livelihoods interconnected? To what extent is water scarcity or poor access to water a driver of poverty?

WORK PACKAGE 2:
Water availability. What is known about water flows, balances and hazards? To what extent is water scarce, where and for whom? What are water-related risks for livelihoods of the poor?

WORK PACKAGE 3:
Agricultural water productivity. How much "crop per drop" is being obtained? Why is water productivity higher in some areas than in others? How might water productivity be improved?

WORK PACKAGE 4:
Institutional analysis. What are the institutional drivers of water and food issues, and their solutions? Who can help change things? Which institutions might resist change? How are institutions interconnected?

WORK PACKAGE 5:
Intervention analysis. What are specific opportunities and risks for change? How can policy change and institutional innovation foster technical change? What are the likely catchment- and basin-level consequences for different water uses and users of introducing alternative change scenarios? Who wins and who loses?

WORK PACKAGE 6:
Information management. How can information generated in other work packages be made readily available for other users?

Outputs from different work packages feed into others, culminating in outputs from Work Package 5 on intervention points for addressing water, food, and poverty issues.

Some results from the first round of BFPs [1]

WATER AVAILABILITY

There are very substantial differences among the benchmark basins studied by first round BFPs. Some basins are very large while others are remarkably small. The Mekong basin, for example, covers more than 0.81 M km^2 while the Karkheh only covers 0.05 M km^2. Most first round basins are sparsely populated (in relative terms), compared to round two basins. The São Francisco, Limpopo and Volta basins have population densities of 18,

1 Adapted from Harrington et al 2008.

43 and 46 persons per km^2, respectively, compared to the Ganges, Indus and Yellow basins with 400, 165, and 156 persons per km^2, respectively.

Water is relatively abundant in some basins and scarcer in others. In terms of rainfall, the Mekong basin is relatively wet, with around 1.4 million cubic meters of rainfall per year per km^2. The drier Karkheh basin receives only 0.4 million cubic meters of rainfall per year per km^2. Per capita water supply may be a better indicator of the extent to which people perceive water to be scarce. It ranges from over 8000 cubic meters per person per year in wet basins like the Mekong or the São Francisco to less than 1000 cubic meters per person per year in drier basins such as the Limpopo.

Within basins there is, of course, considerable spatial variability. A gross way of capturing some of this variability is to distinguish between basins where rainfall is concentrated upstream (Karkheh, São Francisco) vs. those where rainfall it is concentrated downstream (Volta). A typical issue in "dry upstream" basins is how to sustain economic activity, especially agriculture, in upper catchments. In "wet upstream" basins, the effect of upstream water management on downstream communities increases in importance.

WATER USE AND WATER PRODUCTIVITY

Rainfall, water availability, population density and irrigation infrastructure were all found to influence water use. In several basins with low population densities, such as the São Francisco or the Volta, grasslands and woodlands are major users of water. The large proportion of water used for irrigated agriculture in Asia (especially the Ganges and the Karkheh) contrasts sharply with the very low proportion of water used for this purpose in Africa. The proportion of water discharged from the basin into the sea is far higher in wet basins than in dry basins: 37% for the Mekong vs. 2% for the Karkheh.

In the Karkheh, it was found that water productivity tends to be lower in wetter than in drier areas. Integration of livestock with rainfed cropping (where livestock feed on grass or crop residues) resulted in particularly high levels of water productivity. There are opportunities to use spatial mapping of water productivity to ascertain whether practices used in high water productivity areas might be suitable for lower productivity areas.

Even in dry areas, however, water productivity can sometimes be strikingly low. In the Volta, for example, average total rainfall is sufficient to obtain high crop yields. Nonetheless, farmers' yields are typically very low. This was attributed to spatial and temporal variability in rainfall, poor soils, low input use, and poor market infrastructure. In addition to low inherent fertility, many soils in that basin also suffer from negative nutrient balances: more nutrients are taken off than are applied. In general, it was concluded that there are very substantial opportunities to improve water productivity.

WATER AND POVERTY

No simple relationship was found linking between water and poverty. In the Ganges, for example, poverty is concentrated downstream in Bihar, West Bengal and Bangladesh, where water is relatively abundant. In the Nile, wet Uganda is poorer than dry Egypt. The incidence of poverty in the Mekong is relatively low in dry northeast Thailand.

Water availability, access and quality are just a few of the many factors that affect rural livelihoods. Other factors include access to land resources; off-farm employment and remittances from family members; crop selection and yields; agroecosystem diversification including livestock; access to markets and credit; market and transport infrastructure and marketing margins; education; inheritance; expenses associated with starting a new family, or with life transitions such as marriages; or accidents or disease. The interrelationships among these numerous factors are usually complex. While it is clear that water can have a strong influence on crop yields, opportunities for agroecosystem diversification, and the incidence of (water-related) disease, other distinct roles played by water are not always easy to define, even when these roles are important. These conclusions are in accord with those drawn by Theme 2 research projects.

Regardless of causal links between water and poverty, opportunities to reduce poverty through water-related interventions were identified in all round one BFP basins. Improved water management can be an important part of increasing land and labor productivity, producing more food at a lower cost, generating employment and, in general, fostering equitable economic growth.

In analyzing poverty, it was found necessary to take a broader view of the dynamics of development and the processes of rural transformation, including out-migration of farm populations, especially in the Karkheh, Mekong and São Francisco basins. In the Karkheh basin, rural poverty rates have declined over the past 20 years, largely because of rural to urban migration and broader national poverty reduction strategies. The Karkheh basin is less poor than is Iran as a whole and (after adjustments for the cost of living) rural areas of the Karkheh are less poor than urban. Farmers are in the top half of the rural income bracket in the Karkheh. Surprisingly, the poorest rural area of the Karkheh is the lower reach – where irrigated agriculture is concentrated. Irrigation infrastructure is also being damaged by siltation, related to land management practices in upper catchments. As a rule, however, non-agricultural interventions show the most promise for further reducing poverty.

In the São Francisco basin, poverty rates have also declined. There has been a strong out-migration of smallholder farm families, some to urban areas but others to seek jobs in large commercial farms specializing in high value crops for export. Water x food x poverty links are in part related to employment opportunities and wage rates in large farms, and the extent to which commercial high value crops require irrigation.

In the Mekong basin, the shape of rural transformation varies by country and in some instances within countries. Poverty has been found to be concentrated in "remote rural highlands". Poverty is relatively low in northeast Thailand, where people take advantage of income-earning opportunities in rapidly growing urban centers such as Bangkok. Agriculture in northeast Thailand is becoming less important in livelihood strategies. In contrast, water and agriculture remain very important for poor farmers in the hillsides of Laos, or for fisher families near the Tonle Sap in Cambodia.

In the Volta basin, the transformation of rural society is proceeding more slowly. About 40-45% of the rural population is below national poverty lines, while more than 70% live below an income level of $2/day. Poverty and water scarcity both increase in a south to north gradient, with a higher incidence of poverty among subsistence farmers as opposed to cash crop farmers. Farming and livestock herding remain fundamental to the livelihoods of the rural poor, and water scarcity and food security are closely linked. Past success in increasing food production has come more from area expansion than yield increase, and there are concerns about how to meet future food demands for a growing population. Poverty is attributed to such factors as low agricultural productivity, poor soils, poor access to markets, price variability, insecure land tenure, lack of access to good quality domestic water, and water related diseases. Rural to urban migration is important, but does not yet offer a major route out of poverty.

UPSTREAM, DOWNSTREAM

First round BFPs identified a number of instances where upstream changes in land and water management have consequences for downstream populations. In the Mekong, for example, it was found that upstream investments in hydropower would result in only small changes in the volume of downstream river flows – but that even these small changes might be enough to have significant impacts on sensitive fisheries such as the Tonle Sap. In the Karkheh, land degradation associated with upstream land management practices resulted in soil erosion and siltation of irrigation infrastructure.

In the Volta, it was shown that water harvesting to increase crop yields in upper catchments would probably <u>not</u> affect downstream water flows, simply because run-off in these catchments represents such a small proportion of available rainfall. The extent to which further expansion of the area under small reservoirs in upper catchments of the Volta might affect downstream hydropower reservoirs remains unclear.

IMPACT ASSESSMENT AND IMPACT PATHWAYS

The BFP Impact Assessment Project helps projects recognize what sorts of impacts they expect to have, and how these changes will come about. That is, it helps BFPs and other projects within basins to define impact pathways. These have two components (a) causal chains of activities, outputs and outcomes that show how a project achieves its purpose and goal and (b) network maps that show the evolving relationships between project partners, implementing organizations, and ultimate beneficiaries needed to achieve the goal. Impact pathways bring together the best of two models of how innovation occurs – the traditional one based on logical frameworks (log frames); and network models.

Network maps, a key part of impact pathways, portray the multiple linkages found amongst partners, and thus multiple ways in which ideas and technologies can interact and be developed and diffused. This helps people see that they are part of a network, and it is the network, not just their own organization, that will achieve impact. It helps people appreciate that the interactions between actors make the innovation process inherently unpredictable in the medium and long-term.

Developing impact pathways helps projects better understand and communicate what it is doing, with whom, and why. This helps the project focus on high priority activities and relationships. Moreover, constructing impact pathways helps identify complementarities and synergies between projects, and facilitates monitoring and evalua tion.

Impact pathways workshops were held for the Karkheh, Mekong, and Volta BFPs in 2006. During 2007, such workshops were held for the new, second round BFPs in the Limpopo and Yellow river basins. Beginning in 2008, impact pathways will be used in the monitoring and evaluation of second call competitive grant projects and second round BFPs. Every six months, projects will be asked to reflect on progress along their impact pathways, with the help of an Impact Pathways Workbook. Based on this reflection, they will send a brief report to the CPWF.

TOWARDS THE FUTURE

Future trends were identified that, as they unfold, will affect water and poverty, and opportunities to reduce poverty and improve equity through water-related investments. These trends include demographic change, climate change, and the continued transformation of rural society. In most basins, the continuation of these trends will involve trade-offs – between upstream and downstream communities, energy and food production, agriculture and fisheries, and economic development and environment. Getting the balance right in these trade-offs will require good governance at local, regional, and basin scales.

SUMMARY

FP findings indicate that the notion of a "water and food crisis" must be defined very differently in different basins, and even in different parts of the same basin. The concept of "more crop per drop", while vivid and useful, must be interpreted and operationalized to fit local circumstances. BFPs have found that much more is known about the state of water on the one hand, and the state of food security and poverty on the other, than is known about how they interact and influence each other. Links between water and poverty tend to be complex and subtle; rarely is it found that people are relatively poor simply because they have relatively less water. Water effects on livelihoods can be manifested in many different ways.

Water productivity has proven to be an extraordinarily useful and powerful concept. Drivers of spatial variability in water productivity, however, are often difficult to define. Numerous technical interventions to improve water productivity and food security have been identified by BFPs. However, the successful introduction of new technology often depends on getting particular institutional innovations in place and that these, in turn, depend on getting policies or governance right. Understanding and quantifying the consequences of such "intervention sets" often requires a combination of powerful modeling tools an

Capacity-building

The Challenge Program on Water and Food (CPWF) provides opportunities for scientific mentorship and capacity building for understanding and measuring water flows, use, governance, and needs within multiple agricultural and ecological systems and at different spatial scales. The capacity building/training activities of special interest are those which build unique skills linked to CPWF themes.

CPWF capacity building within research projects aims to adapt, apply and disseminate research methodologies which build integrative skills linking research approaches for investigating water management, agricultural production, and ecosystem and livelihood resilience. Capacity building activities in projects fall into three major sub-categories: scientific mentorship; specialized skills development; and action research methodologies (see Table 1 for the distribution of these training activities by project number and basin).

"Scientific mentorship" includes informal activities such as advising; network building; attendance and/or opportunities to present at conferences or seminars; interdisciplinary exposure; and research planning and management. These activities are primarily targeted toward NARES scientists, but also include NGOs as beneficiaries.

"Specialized skills" are targeted primarily for researchers to improve technical skills associated with a particular analytical task related to the research project. Specialized skills are built through short term and long term training, including research support to university students at undergraduate, post-graduate and post-doctoral levels.

"Action research methodologies" belong to a family of research tools which simultaneously pursue action (or change) and research (or understanding). Action research has been applied by the CPWF on a range of topics, including measuring water productivity and participatory technology development and assessment. Action research methodologies include training across a broad range of stakeholders, including farmers.

A major achievement of the CPWF's Capacity Building initiative has been to support around 300 students from 24 countries, most of them assigned to cross-thematic CPWF projects, and over 61 per cent living in African countries. Most students focus on water-related fields, with a greater emphasis on the biophysical sciences than the social sciences. To extend CPWF knowledge and methodologies from its research projects to the widest possible pool of beneficiaries, its strategy for capacity building promotes partnership with existing education and training structures. The ultimate goal is to increase the ability of scientists to carry out integrated research on water and food.

Activities in 2007 [1]

In 2007, efforts concentrated on seeking funding and strategic partners in Europe and the United States to facilitate the development and implementation of two activities described within the CPWF Capacity Building strategy: 'cohorts' and theme-based 'applied field courses'.

COHORTS: MOU BETWEEN CPWF AND THE INTERNATIONAL FOUNDATION FOR SCIENCE

The International Foundation for Science (IFS) is an international organization that provides small competitively awarded research grants and supportive programming to early career researchers from developing countries. A MOU between IFS and CPWF, signed in July of 2007, secured an annual joint call for proposals, to boost applicant numbers to IFS coming from CPWF basins.

In the agreement, CPWF provides the scientific mentorship for interdisciplinary teams of scientists—IFS cohorts—who develop applications for the IFS grant. The CPWF mentorship is in the form of a per-grantee cash commitment, primarily for biannual workshops which ultimately draw members for the grantee teams. The workshops feature CPWF researchers as technical trainers. As part of its normal programming, IFS provides assistance for all applicants, through proposal writing assistance, team support and travel grants.

COHORTS: VOLTA BASIN SEMINAR AND PROPOSAL WRITING WORKSHOP

The first activity under the IFS MOU was a November workshop held at The International Institute for Water and Environmental Engineering (2iE) in Ouagadougou which hosted 20 applicants from five of the six Volta Basin countries. Applicants were recruited through a call for proposals posted on the CPWF, IFS, and 2iE websites and publicized through the CPWF Volta Basin network. Participants received mentorship on research methodologies and proposal writing from IFS and 2iE staff, as well as from seven CPWF scientists from the Small Reservoirs Project, the Rainwater and Nutrient Use Efficiency Project, the Transboundary Water Project, and the Volta Basin BFP.

Collaboration with 2iE, an important regional institute of higher education for the water sector, brought a new partner into the CPWF Volta Basin network, and permit-

1. This and following paragraphs are drawn from the CPWF Annual Report 2007

ted the CPWF to contribute to 2iE's planned expansion of research activities, increasing the presence of English speaking scientists, students and instructors onto their largely francophone campus. Participation of CPWF scientists strengthened interactions and exchanges between institutional partners, both inside and outside of the basin, enabling the longevity of its collaborative approaches to exist beyond the program's timeframe.

Afterword

The Challenge Program on Water and Food represents the response of the CGIAR system to a problem of global significance: water scarcity. It recognizes that competition for water is an important part of a larger set of problems involving poverty, food insecurity, and environmental degradation, and that increased water productivity in agriculture is a critically important factor in overcoming these problems.

For the past several years, the CPWF has planned and carried out a strategically-focused and innovative program of research, development and capacity-building. During this time, the Program has identified innumerable ways in which water productivity can be increased through technical change, institutional innovations, and appropriate policies. It is developing methods that show how the adoption of scientific innovations affects different water users and uses across scales—including the environment. In effect, the CPWF is showing what can be done when partnerships fully harness their creativity and experience to address enormously complex but supremely important problems.

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

Project Number	Project name	Basins
PN1	Increased Food Security and Income in the Limpopo Basin through Integrated Crop, Water and Soil Fertility Options and Public-Private Partnerships	Limpopo
PN2	Improving Water Productivity of Cereals and Food Legumes in the Atbara River Basin of Eritrea	Nile
PN5	Enhancing Rainwater and Nutrient Use Efficiency for Improved Crop Productivity, Farm Income and Rural Livelihoods in the Volta Basin	Volta
PN6	Empowering Farming Communities in Northern Ghana with Strategic Innovations and Productive Resources in Dryland Farming	Volta
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
PN8	Improving On-farm Agricultural Water Productivity in the Karkheh River Basin	Karkheh
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
PN11	Rice Landscape Management for Raising Water Productivity, Conserving Resources and Improving Livelihoods in Upper Catchments of the Mekong and Red River Basins	Mekong
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
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)
PN16	Developing a System of Temperate and Tropical Aerobic Rice (STAR) in Asia	Indus-Ganges, Mekong, Yellow
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
PN20	Sustaining Inclusive Collective Action That Links across Economic and Ecological Scales in Upper Watersheds (SCALES)	Andes, Nile
PN22	Payment for Environmental Services as a Mechanism for Promoting Rural Development in the Upper Watersheds of the Tropics	Andes, Nile
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
PN25	Companion Modeling for Resilient Water Management: Stakeholder's Perceptions of Water Dynamics and Collective Learning at the Catchment Scale	Mekong
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
PN30	Wetlands-Based Livelihoods in the Limpopo Basin: Balancing Social Welfare and Environmental Security	Limpopo
PN34	Improved Fisheries Productivity and Management in Tropical Reservoirs	Indus-Ganges, Nile, Volta
PN35	Community-Based Fish Culture in Irrigation Systems and Seasonal Floodplains	Indus-Ganges, Mekong
PN36	Improved Planning of Large Dam Operation: Using Decision Support Systems to Optimize Livelihood Benefits, Safeguard Health and Protect the Environment	Nile
PN37	Increasing Water-Use Efficiency for Food Production through Better Livestock Management - The Nile River Basin	Nile
PN38	Safeguarding Public Health Concerns, Livelihoods and Productivity in Wastewater Irrigated Urban and Peri-Urban Vegetable Farming in Ghana	Volta
PN40	Integrating Knowledge from Computational Modeling with Multi-Stakeholder Governance: Towards More Secure Livelihoods through Improved Tools for Integrated River Basin Management	Andes, Volta
PN42	Groundwater Governance in Asia: Capacity Building through Action Research in Indo-Gangetic (IGB) and Yellow River (YRB) Basins	Indus-Ganges, Yellow
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
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
PN48	Strategic Analysis of India's National River-Linking Project (NRLP)	Indus-Ganges
PN50	Multi-scale Mekong Water Governance: Inter-disciplinary Research to Enhance Participatory Water Governance from Local Watershed to Regional Scales	Mekong
PN51	The impact of waste water irrigation on human health and food safety among urban communities in the Volta Basin – opportunities and risks	Volta
PN52	Strengthening Fisheries Management Institutions in the Lower Mekong River Basin through Collaborative Research and Data Synthesis across Multiple Scales	Mekong
PN53	Food and water security under global change: developing adaptive capacity with a focus on rural Africa Nile,	Limpopo

Annex 2: List of acronyms and abbreviations

2iE	International Institute for Water and Environmental Engineering
ACIAR	Australian Council for International Agricultural Research
ADB	Asian Development Bank
APSIM	Agricultural Production Systems sIMulator [sic]
BFP	Basin Focal Project
BRRI	Bangladesh Rice Research Institute
CA	Comprehensive Assessment of Water Management in Agriculture, also used for “conservation agriculture”
CGIAR	Consultative Group on International Agricultural Research
CPWF	Challenge Program on Water and Food
CRS	Catholic Relief Services
CURE	Consortium for Unfavorable Rice Environments
CWANA	Central and West Asia and North Africa
DFID	Department for International Development (UK)
DPSIR	Driver, Pressure, State, Impact and Response (framework)
DSS	Decision support and information systems
DSSAT	Decision Support System for Agro technology Transfer
EPIC	Erosion Productivity Indicator
FAO	Food and Agriculture Organization
FDC	Flow duration curve
GATS	General Agreement on Trade in Services
GAWI	Global Agriculture and Wetland Interactions
GCM	Global circulation model
GEF	Global Environmental Fund
GIS	Geographic information system
GPS	Global positioning system
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Agency for Technical Cooperation)
GWSP	Global Water Systems Project
HAB	Harmful algal blooms
HRU	Hydrological response unit
IBWMS	Integrated basin water management systems
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFAD	International Fund for Agricultural Development
IFWF	International Forum on Water and Food (November, 2006, Vientiane)
IFS	International Foundation for Science
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
INGER	International Network for Genetic Evaluation of Rice
INRM	Integrated natural resource management

IPCC (SRES)	Intergovernmental Panel on Climate Change Special Report on Emission Scenarios
IPG	International public good
IRRI	International Rice Research Institute
IRSSTON	International Rice Soil Stress Tolerance Nursery
IUCN	The World Conservation Union
IWMI	International Water Management Institute
IWRM	Integrated water resource management
LA	Learning alliance
M-POWER	The Mekong Program on Water, Environment and Resilience
MAS	Marker-assisted selection
MIKE SHE	(An integrated hydrological modeling system, acronym source unknown)
MOU	Memorandum of understanding
MRC	Mekong River Commission
MTP	Medium-Term Plan
MUS	Multiple-use systems
MWRAS	Mekong Water Resources Assistance Strategy
NARES	National agricultural research and extension systems
NGO	Non-governmental organization
NIA	National Irrigation Administration (Philippines)
NRLP	National River-Linking Project
PRA	Participatory rapid appraisal
PDRD	Program for Sustainable Rural Development
PES	Payment for environmental services
PPB	Participatory plant breeding
PVS	Participatory varietal selection
QSMAS	Quesungual slash-and-mulch agroforestry system
QTL	Quantitative trait loci
RWS	Relative water supply
SAR	Synthetic aperture radar
SEF	Sahelian/ Sudanian Eco Farm
STAR	System of temperate and tropical aerobic rice
UPA	Urban and peri-urban agriculture
VBSE	Village based seed enterprise
WEAP	Water Evaluation and Planning
WHO	World Health Organization
HS	Water harvesting systems
WRC	Water Resources Commission (Ghana)
WTO	World Trade Organization

Annex 3: The Vientiane Statement

WE, the scientists, development workers, and representatives of civil society gathered together in Vientiane, at the CPWF "International Forum on Water and Food", agree to and state the following:

The challenge

We recognize the huge global problems posed by hunger, poverty, and disease. These same problems inspired the adoption of the Millennium Declaration by the United Nations. We recognize the many obstacles to overcoming these problems, among them climate change, resource degradation, and impaired ecosystems. We perceive, however, the presence of a further issue of paramount importance, one that must be addressed if the Millennium Development Goals are to be achieved: the rapidly unfolding and unprecedented crisis of global water scarcity.
Growing and urbanizing populations will need more water for household consumption, power generation, and industrial production – and for increased food production and the provision of important ecological services. Over the next 20 years, food production must increase by over 30%, much of it in poor, water-scarce developing countries. This must be achieved without excessive damage to ecosystems.

The vision

We seek a more water and food secure world, one where wise water management, innovative technologies and effective institutional arrangements work together towards eliminating hunger, poverty and disease, and where ecological services and resource quality are preserved. Such a world is within our reach.

The strategy

The best place to start is with food production as agriculture is by far the largest single water user. By using less water to produce more food, more water can be made available for nonagricultural purposes. Poverty can be reduced and food security improved when smallholder farmers and subsistence fishers achieve higher levels of sustainable productivity. A suitable strategy must also embrace more holistic and equitable water allocation and use in communities, catchments and river basins. Concrete actions are needed at multiple scales by multiple actors . . .

ON FARMS AND AGRO ECOSYSTEMS

Develop farming practices that sustainably improve land and water productivity. In rainfed areas these include water harvesting, small-scale irrigation, conservation agriculture, and stress-tolerant crop varieties. In grazing areas, better rangeland management can improve livestock productivity while reducing soil loss. In irrigated areas, new technologies can sustainably increase crop yields while reducing water withdrawals. Risk and disaster management strategies are needed, especially in drought or flood-prone areas. In all areas, diversification can increase the value of output per unit of water depleted, while improving resilience. Diversification may feature integration of livestock, fishing, crops and trees.

Widespread adoption of sustainable, productive, water-wise farming practices emerges from dynamic innovation systems. These must be encouraged. Experience shows that innovation can be accelerated during crises. These opportunities must be seized – in ways that help the poor and vulnerable.

IN LOCAL COMMUNITIES

Involve local stakeholders in water management decision-making. Participatory technology development that makes use of traditional knowledge and the capacity of farmers and fishers to find solutions to their problems is indispensable. Educational initiatives are needed to build this capacity.

Introduce multiple-use water systems. Most people use water for a multiplicity of domestic and productive purposes. Unfortunately, water supply systems are usually designed for a single use, e.g., irrigation. Such systems are often unable to cope with additional demands. Where appropriate, water systems that are multiple-use by design should be introduced. Diverse water sources should also be explored—such as waste water. Attention must be paid at all times to the ways that water effects human health.

Improve gender equity and introduce gendered research agendas. Women play a central role in food production, natural resource management, and communities and the livelihoods of rural families. Improved gender equity is a means of achieving food security and poverty-reduction goals, as well as a goal in itself.

Reduce groundwater depletion. In several major regions, e.g. the western Ganges, and Yellow River, groundwater depletion threatens the food security and livelihoods of hundreds of millions of people. A combination of new water management practices and policies for common property management are needed.

IN WATERSHEDS AND RIVER BASINS

Improve communication and collaboration among water users. Water is often a source of conflict, e.g., between upstream and downstream users or across national borders. Raw power often determines who has access to water resources. Dialogue among stakeholders can, however, foster awareness of each others' interconnected needs, leading to more efficient, equitable water allocations and, where appropriate, a shift from sharing water to sharing benefits derived from water use.

Encourage payments for environmental services. Inappropriate upstream land and water use can damage downstream ecologies and people's health. Downstream stakeholders may need to provide incentives to upstream people to allow greater flows of higher quality water. This can be done in ways that build on existing policies and institutions, foster social cohesion and create awareness among stakeholders.

Recognize the value of ecological services and environmental flows. Within a basin, aquatic and land management systems produce ecological services such as clean water, fresh air and the preservation of biodiversity. The services are difficult to value, whereby their importance is often not fully appreciated. The same is true for environmental water flows – the water required to maintain downstream ecologies.

FOR NATIONAL AND GLOBAL POLICIES AND INSTITUTIONS

Improve water use governance at all scales. Questions of governance are most challenging at higher scales of analysis, e.g., entire river basins. Here, 'command and control' governance systems are less suitable than those based on stakeholder participation. For the latter to work, however, innovative legislative frameworks are needed. Transboundary water policies are most likely to be acceptable, effective, and equitable when they focus on benefit sharing, not water sharing. Transboundary cooperation in water use is a question for governments, the private sector and civil organizations.

Introduce policies and develop institutions that encourage equitable and efficient water use in ways that reduce poverty and improve food security. Water management is often influenced by national- and global level policies that are outside the water sector, e.g., trade or energy policy, crop price support or input subsidies. Policies also play a proactive role, e.g., by fostering the use of conservation agriculture or by giving priority to rehabilitating degraded lands. Harmonizing national and international water polices helps, as does the integration of sectoral policies, e.g., energy, hydrology, transport and agriculture.

A call for action

WE CALL FOR MORE RESEARCH ON:

- Sustainable, productivity-enhancing, water-saving farming practices adapted to local conditions
- Risk management for vulnerable communities (e.g. rain-fed farmers and subsistence fishers)
- Ways to sustainably increase water productivity in aquaculture and livestock production
- Ways to manage conflicts among alternative water uses and users; along with decision-support systems and scenario analysis to backstop dialogue among stakeholders
- Links between gender and resource management and land and water productivity issues
- Methods for valuing ecological services and for estimating environmental flows
- The consequences of climate change on land and water productivity, food security, and poverty.

WE CALL FOR GREATER INVESTMENT IN:

- Capacity-building in multidisciplinary and integrative approaches for researchers, development workers, and water management stakeholders

- Programs for participatory technology development; aquaculture development in large and small reservoirs; and programs of payments for environmental services

- Programs for fostering widespread adoption of successful farm level interventions

WE CALL FOR POLICIES THAT:

- Encourage the use of farm-level practices that sustainably improve land and water productivity; encourage wise use of groundwater; and foster land use congruent with ecological reality

- Establish regulatory frameworks that recognize multiple uses and users and empower local and indigenous water management systems

- Foster a greater and more systematic sensitivity to gender issues

- Establish legislative frameworks for river basin governance systems based on stakeholder participation and suported by adequate information and decision-support

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